THE WORKS ENGINEER

A PRACTICAL MANUAL ON
BUILDING AND PLANT MAINTENANCE
FOR THE WORKS MANAGER AND
WORKS ENGINEER

BY

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TECHNICAL STAFF, THE INSTITUTION OF MECHANICAL ENGINEERS

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PREFACE

THE compiling of this book would not have been possible but for the assistance I have received from different firms, also from members of my staff.

The greater part of the data has been taken from my technical reference files, as mentioned in Chapter I, and wherever possible due acknowledgment has been made to those concerned. If the name of anyone has been missed, I crave his indulgence; should a further edition be published due credit will be given to him.

I have endeavoured to be as brief as possible, owing to the variety of subjects covered, and have included only such formulae as are essential.

Any one chapter would form a book in itself, and where the reader wishes to delve further into any one subject, a list of suitable literature is given in the Bibliography, page 348. Some of these items are manufacturers' technical publications, which may be had for the asking, and others are technical books, but in each case the author can recommend them.

W. R. J. G.

CONTENTS

THE WORKS ENGINEER

CHAPTER I

OFFICE ORGANIZATION AND ROUTINE

WHILST there are many books which deal with works organization, boiler costs, machine maintenance, factory buildings, etc., there are few that cover the whole of the maintenance organization of a works. The object of this book is to give a general reference book on maintenance for the use of the Works Manager and the Works Engineer.

The endeavour has been, not so much to make a technical reference book, as to cover problems on maintenance such as are likely to come up in a works, and systems that have been tried and proved successful; and to offer suggestions as to where savings can be effected, and on the use of general service records.

In some works it is still the practice to put different maintenance and service sections under different departmental heads; and apart from the overlapping and waste of time that must in consequence take place, maintenance is sure to cost considerably more than if it is all under the direction of a capable engineer.

It is essential in industry to-day to reduce the non-productive labour costs to a minimum, and the same applies to the necessary services: electricity, steam, gas, air, and water. This can only be done by making the Works or Plant Engineer responsible for the linking up and economical running of all these departments. When a large organization has several works, a considerable saving can be effected if one engineer is made responsible for all the works, if only in a consultative capacity, his office being situated as nearly geographically central between the different works as is possible. Improvements in any one works will then be handed on to the others; also the pooling of spare or surplus service plant will considerably reduce idle standby plant costs.

Plant such as electrical equipment, pumps, meters, tanks, and even boilers, which have been replaced by higher-pressure or larger-capacity equipment, can very often be used conveniently at other works. This also applies to plant records, etc. It is much easier for the auditors to check the equipment at the different works if the same system is in use at all the branches of an organization.

Office Organization. The hub on which the maintenance departments revolve is the Plant Office. However well equipped with

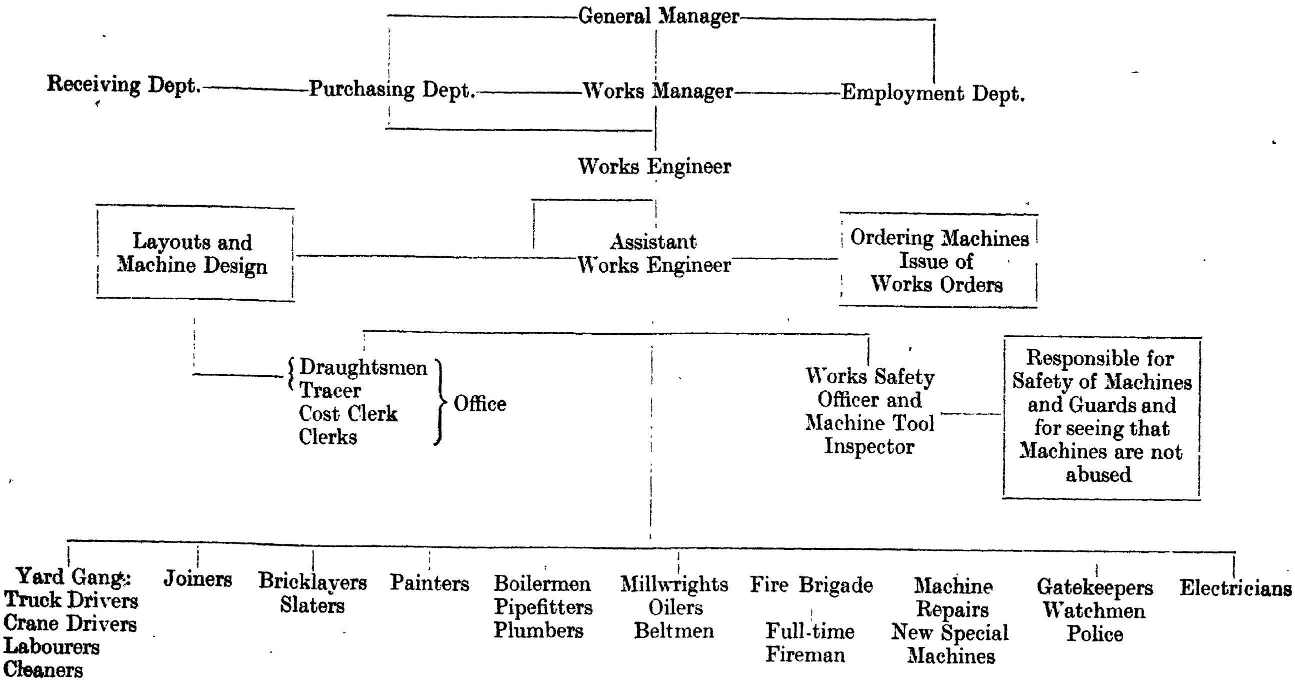


FIG. 1. "TREE" DIAGRAM OF MAINTENANCE STAFF
Showing how different sections should be related.

up-to-date plant and machinery a works may be, it is essential that an adequate staff be kept to maintain such machinery in a first-class state of repair, to watch repair costs, power, light, and service consumptions, and to co-ordinate the different departments. A "tree" diagram (Fig. 1) shows how the different sections should be related.

The Works Engineer is responsible, through the Works Manager, to the General Manager for the maintenance of all the machinery and plant in the works, and for the personnel concerned therewith, as shown in Fig. 1. He is also concerned with the introduction of new equipment to supplement or replace existing plant, and with the planning of the layout of the shops and the choice of design of the actual machines. In some large works, however, there is a Planning Engineer who is responsible for the last-mentioned duties.

The Works Engineer must be able to adapt the plant to meet the demands made by those in charge of actual production, or by those individuals who have planned the works. It sometimes happens, however, that the duties of planner and Works Engineer are combined, and in such a case the official holding this position would do well to invite suggestions from the different repair sections regarding improved methods, both in keeping the plant in the highest state of efficiency, and in the best and quickest ways of effecting repairs.

It is found advantageous in a large works to employ one or more machine tool inspectors under the Works Engineer on these duties, one inspector undertaking also the duties of Safety Officer.

The machine repair foreman must work in close co-operation with these engineers, reporting to them on the repairs necessary to machines, and indicating whether a machine is worn out, or whether it is fundamentally unsatisfactory. The inspectors are thus frequently able to provide reasons why a certain machine should be replaced, and indications are then made on the plant card (Fig. 4) in such cases.

In most works to-day some kind of progress system is in operation, and the Works Engineer should ensure that any breakdown of a machine should be immediately notified to the Progress or Planning Office, as it may be possible to make temporary arrangements to meet the emergency; whereas if the Progress Office were not promptly advised, dislocation of the programme would speedily ensue. The Progress or Planning Office should then ascertain from the millwrights or repair section how long the machine will be out of action. If a new part or parts are required, constant watch must be kept on the orders, to ensure that the least possible time is taken for their completion. Here the value of periodic inspection of the plant is apparent; and a regular survey of all machines by the foremen concerned, and of all electric motors and equipment by the electricians, will go far in reducing breakdowns to a minimum.

ORDER REQUISITION 43100

CAPITAL AND EXPENSE.

ENTER ORDER ON Section 36 DEPT.

TO Make 12 Ball Bearing Wire Guide Pulleys

REMARKS for Coil Winding M/cs.

Order No X 37004

SIGNED WRG pp [illegible]

DATE 6. 10. 37.

APPD.

DATE

CHARGE TO F.P.M. 23

ESTIMATED COST

MATERIAL £1 : 7 : 0.

LABOUR £1 : 5 : 0.

FIG. 2. PAGE FROM ORDER BOOK

Assistant Works Engineer. This official is responsible for issuing the orders for new plant, works orders for alterations and additions to services, repairs, etc. A good pattern of order book in duplicate form is illustrated in Fig. 2; separate books of this type should be kept for new plant, repairs, and for orders on Purchasing Department. The estimated cost of the job, also the section to whom the cost of the job is to be charged, is put on the order. The estimate shows material and labour costs separately, whilst the charge is shown by a symbol letter (e.g. L = Lighting; F = Furniture, etc.) followed by the section number.

It might be noted here that all sections are known by numbers, and on all time cards, requisition notes, inter-departmental orders, etc., these numbers appear in lieu of naming the section. The orders are taken each day before the Works Manager, who initials them, tearing out the top copy, which goes before the General Manager for his sanction. When sanctioned, it is passed to the Main Order Office and a typed order is issued. This may seem somewhat complicated, but it enables the Works Manager to see the expenditure on the different departments, also giving him the opportunity of withholding sanction for a job if he feels there is not a good case for it. In addition, it also enables the General Manager to know the amount of money that is being expended. The official order being issued by the Main Order Office means that copies go to the Costs Department in the usual routine way. (An alphabetical record is kept in the Plant Office, of purchasing and "X" (expense) orders for ready reference.) Should the actual cost exceed the estimated, these orders are put before the General Manager.

To check these costs, all shop orders, when completed, are sent by the foreman concerned to the office, to be closed; whence they are sent in turn with a slip, illustrated in Fig. 3, to the Costs Department. Here they are checked for actual as against estimated cost. If this difference is more than, say, £2 and it is justifiable, a supplementary order is put out; if not, it is passed on to the General Manager, who calls for a report. Thus foremen watch the cost of every job very carefully. All work is booked against works orders, time cards being sent in each week, or at the close of an order, to the Costs Department. Small jobs, such as adjustment of countershafts, are issued on monthly orders for each department in which the repairs are carried out, enabling a close watch to be kept of the monthly cost to each department. Materials are ordered on a material card from the stores against the order number, the stores sending the material cards to the Costs Department. All monthly order costs are sent to the Works Manager each month.

I.D.O.'s. In the case of small orders of a value not exceeding £2, an Inter-Departmental Order (I.D.O.) is issued, which only requires the signature of the superintendent of a department.

Plant. Inquiries for new plant are sent, with full particulars as to machine and firm, to the Purchasing Department, who on receipt of quotations forward them to the Plant Office. If it is decided to order a machine, a plant card, Fig. 4, is made out, on which full particulars are copied from the quotation, the Plant Number being

Mr. Smith THIS ORDER IS NOW READY FOR CLOSING. DATE:- 27-7-34.
SECTIONS ON ORDER. 36, 43.
DESCRIPTION. Make One Flat Deck Shop Trolley with rubber tyred wheels. Trolley sizes. 3′9″ x 1′-6½″ Estimated cost £5/-/-
DATE OF ISSUE. 13.7.34. X. No. 38555.

FIG. 3. ORDER CLOSING SLIP

left blank. When the machine is delivered, the fact is entered in the Plant Book, Fig. 5, and the machine is given a Plant Number, which is then filled in on the card and filed in the plant drawer in numerical order, a note being sent to the Foreman Millwright, who has a brass tab bearing the number fixed on the machine. Any modification as to the price of the machine is checked from the invoice, which is sent to the Works Engineer to initial and pass; thus a check is kept on all incoming machinery. The Foreman Millwright sends a note to the office in duplicate saying when a machine is ready for running, and this is initialled by the Works

Manager, a copy also being sent to the Production Engineer. On the back of the plant card, Fig. 4, all repairs are entered, so that a check is kept on the cost of maintenance of every machine. When a machine requires repairs, the date, order number, and nature of repairs, together with estimated cost (in pencil) are noted on the card, and the card removed to the "Awaiting Cost" drawer, until the actual cost of repair is sent from Costs Office; the actual cost

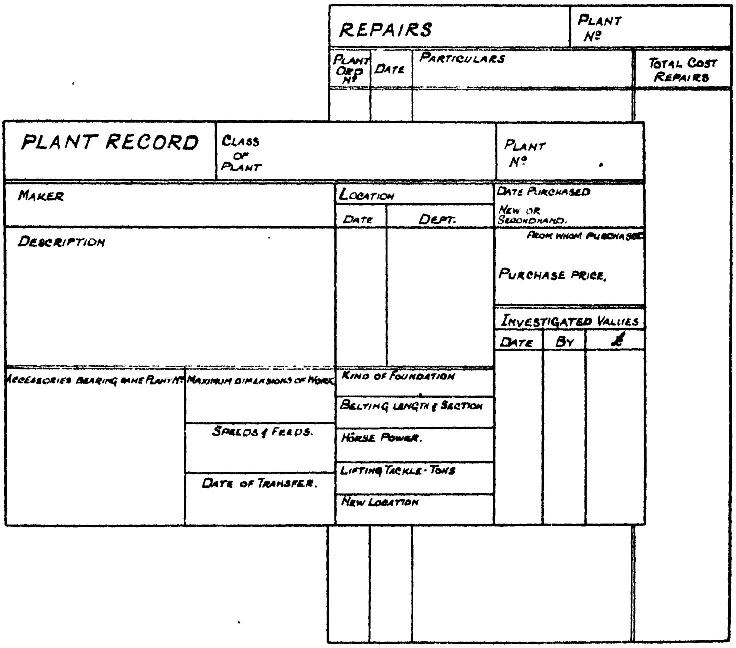
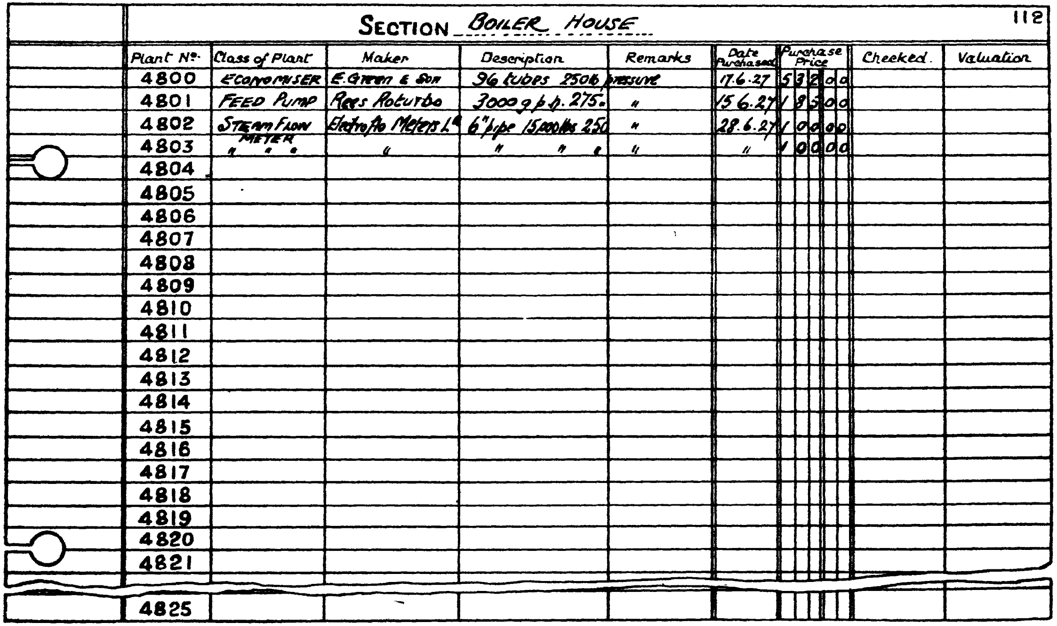


FIG. 4. PLANT RECORD CARD

is then "inked in" and the card is filed in its respective drawer. Whilst the author has used the above system for over eleven years, it has one disadvantage, namely, the use of loose cards, and the possibility of losing a card. A more expensive but better method is to use a *Visible Card Index System* instead of the plant cards, as shown in Fig. 6, and the author has recently changed to this system. The only modification is that a celluloid strip—a standard production of the Card Index Companies—is fitted to the bottom of the card and a loose strip is typed with the particulars. When the card is made out from the quotation, a red celluloid signal is slipped in over the plant number space. When the machine is installed and quotation passed for payment, the red signal is taken



SECTION BOILER HOUSE 112

Plant No.	Class of Plant	Maker	Description	Remarks	Date Purchased	Purchase Price	Checked.	Valuation
4800	ECONOMISER	E. Green & Son	96 tubes 250lb	pressure	17.6.27	532 0 0		
4801	FEED PUMP	Rees Roturbo	3000 g.p.h. 275.	"	15.6.27	185 0 0		
4802	STEAM FLOW METER	Electroflo Meters Ld	6" pipe 15000lbs 250	"	28.6.27	100 0 0		
4803	" " "	"	" " "	"	"	100 0 0		
4804								
4805								
4806								
4807								
4808								
4809								
4810								
4811								
4812								
4813								
4814								
4815								
4816								
4817								
4818								
4819								
4820								
4821								
4825								

FIG. 5. TYPICAL PAGE FROM PLANT BOOK

out. If a machine is under repairs, instead of moving the card, a green signal is inserted in the space marked "Repairs," and removed when the job is completed, the cost being filled in on the back of the card. There is also a space for "obsolescence." If the repair costs for any machine are exceptionally high, a black signal is fitted in, the object being to draw attention to the machine in question,

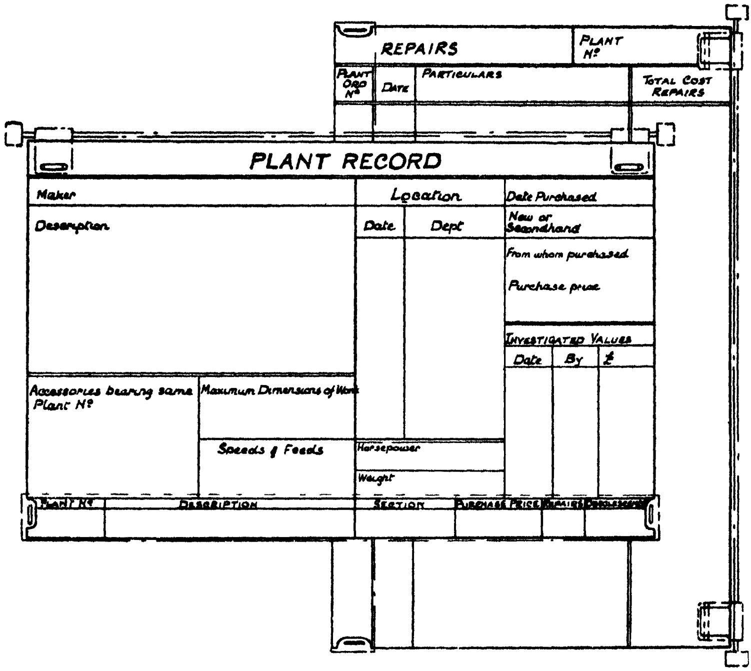


FIG. 6. PLANT CARD FROM "VISIBLE INDEX" FILE

and to the advisability of replacement; this signal can similarly be used when the output of a machine is low.

When a machine is condemned for scrap, the fact should be recorded on the card, by entering the words "Broken up," or "Scrapped," as the case may be, and the date. In order to avoid confusion in the file, the complete history of the machine appearing on the original card is copied on to a card of another colour (say, blue); the original card is removed from the file and the blue card substituted in its place. The original cards thus removed can be kept in a special file referring to machines scrapped. A similar procedure may be followed in the case of machines sold to other firms, a card of a different colour (e.g. green) being substituted for

the original card, which is removed to a special file recording machines sold. These files thus show a complete history of all the equipment in the works from the time that the system was put into operation. The system can be usefully extended to such items as electric motors and generators.

It will be seen that such a system operated in conjunction with the Plant Book, Fig. 5, has much in its favour. The cards are housed

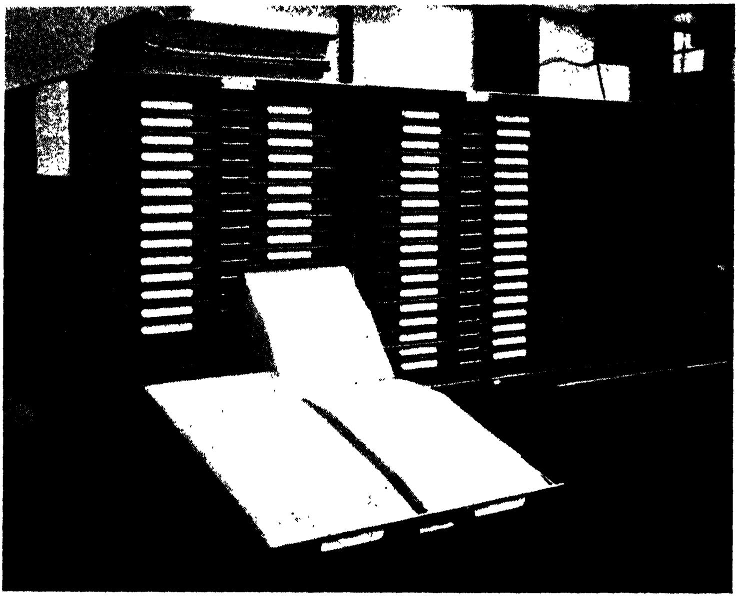
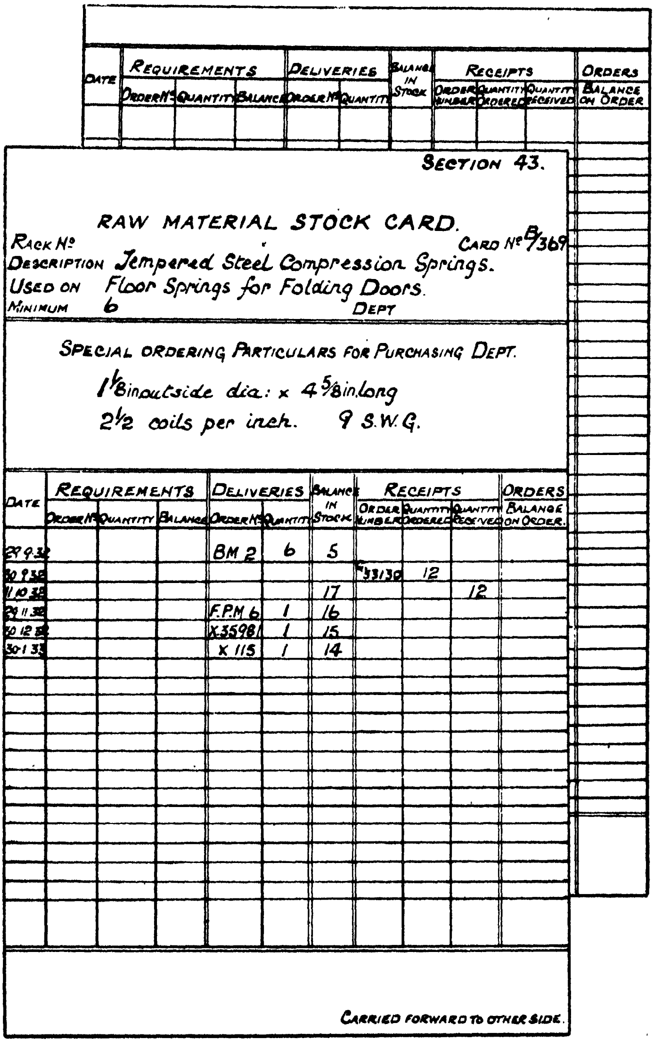


FIG. 7. METAL CABINETS HOUSING CARD INDEXES

in drawers in metal cabinets, and it is possible to visualize every machine in a department, the number under repairs, new machines ordered, and where replacements should be considered. The black signal also gives the Machine Tool Inspector and Safety Officer an indication as to where to look for trouble, and to investigate whether a machine is receiving proper treatment from the operators. An illustration of the cabinets and trays, with a capacity for 10 000 cards, is shown in Fig. 7.

ESTIMATING. All estimates for plant removals, new machines, etc., are entered up in a duplicate Estimate Book, a card index system being kept of prices of materials ordered from outside sources.

Floating stocks, such as steam pipes, fittings, belting, etc., are kept on stock cards, illustrated in Fig. 8, which are self-explanatory.



SECTION 43.

RAW MATERIAL STOCK CARD.

RACK No. CARD No. B/369

DESCRIPTION Tempered Steel Compression Springs.

USED ON Floor Springs for Folding Doors.

MINIMUM 6 DEPT

SPECIAL ORDERING PARTICULARS FOR PURCHASING DEPT.

1⅛ in outside dia: x 4⅝ in long

2½ coils per inch. 9 S.W.G.

DATE	REQUIREMENTS			DELIVERIES		BALANCE IN STOCK	RECEIPTS			ORDERS
	ORDER No.	QUANTITY	BALANCE	ORDER No.	QUANTITY		ORDER NUMBER	QUANTITY ORDERED	QUANTITY RECEIVED	BALANCE ON ORDER.
29.9.32				BM 2	6	5				
30.9.32							S 33/30	12		
11.10.32						17			12	
29.11.32				F.P.M 6	1	16				
30.12.32				X 35981	1	15				
30.1.33				X 115	1	14				

CARRIED FORWARD TO OTHER SIDE.

DATE	REQUIREMENTS			DELIVERIES		BALANCE IN STOCK	RECEIPTS			ORDERS
	ORDER No.	QUANTITY	BALANCE	ORDER No.	QUANTITY		ORDER NUMBER	QUANTITY ORDERED	QUANTITY RECEIVED	BALANCE ON ORDER

FIG. 8. MATERIAL STOCK CARD

These cards are sent in by the storekeeper (when his stated minimum stock is reached) to the office for ordering these articles, and are initialled by the Works Manager or Works Engineer before replacements are ordered.

1933	Corporation Meter		Turbo Alternator	Rubber Works			No 3 Factory			Condenser Shop.
Date	Power & Light			Meter "L" Less No 3 Fac. Cond. 50 H.P. Air CompS & Well Pumps			Meter "P" Less Cond. & No 3 Well Pump			Power
Wk Endg	Reading	Consumption	Generated	Reading	Consumption		Reading	Consumption		Consumption
Mar. 4	6 071 550	54 650	9 640	950 607	3685		963 980	932		350
11	6 128 310	56 760	9 560	956 516	2177		965 620	640		350
18	6 186 550	58 240	7 750	963 206	1178	11918	967 220	1250	4331	350
25	6 246 250	59 700	6 550	971 308	4228		969 050	809		350
31	6 298 110	51 860	5 560	974 119	650		970 001	700		250
31	6 299 380	260 550	4 380							
Ap. 8	6 358 980	60 870	3 950	979 462	2250		971 140	789		350
15	6 428 400	69 420	2 960	986 874	4350	13195	972 370	860		350
22	6 473 520	45 120		992 550	2674		973 410	740	3279	300
29	6 535 220	61 700	Spring & Summer Period	999 743	3881		974 630	870		350
30	6 540 740	241 360								
May 6	6 600 020	64 800		7 418	4 521		975 770	790		350
13	6 663 340	63 320		14 633	4 429	18315	976 750	610	2490	300
20	6 728 270	64 930		20 460	3875		977 610	540		300
27	6 794 990	66 720		28 410	5 490					
31	6 833 050	292 310								

FIG. 9. SHEET FROM

SERVICES. All meter readings for steam, gas, power, light, and water are sent to the office weekly and entered up by the costs clerk in the "Consumption Books," one of which—the Electricity Book—is shown in Fig. 9.

A twelve months' chart is hung in the Works Engineer's office showing all consumptions which are entered upon it weekly; these consumptions are dealt with more fully under their separate headings later in the book.

POWER	(FOR CONTINUATION SEE NEXT PAGE)								
CABINET WORKS & FRAME SHOP.			BOILER HOUSE			WIRING SHOP GENERAL STORES HEAT TREATMENT		FINISHING SHOPS	
METER "I"			METER "N"			METER "K"		METER "J"	REMARKS
READING	CONSUMPTION		READING	CONSUMPTION		READING	CONSUMPTION	CONSUMPTION	
438 461	4465		355 070	8790		751 270	4323	1566	
443 272	4811		365 490	10420		756 650	5380	1446	
448 212	4940	22152	374 550	9060	45940	762 890	6250	1464	
453 131	4919		383 820	9270		768 430	5540	1167	
456 148	3017		392 220	8400		772 820	4390	849	
									1150 kVA.
461 070	5922		400 740	8520		778 970	6150	1458	
465 798	4728	18261	410 120	9380	33250	785 160	6190	1473	
470 536	4738		417 290	7170		790 980	5820	960	
473 409	2873		425 470	8180		796 460	5480	1503	
									1150 kVA
479 391	5982		434 400	8930		803 600	7140	1566	
484 411	5020		442 980	8580	33180	810 920	7320	1722	
489 394	4983	21193	450 960	7980		818 510	7590	1764	
494 602	5208		458 650	7690		828 160	9650	1815	

"CONSUMPTION BOOK"

It is occasionally advisable to measure continuously the total power consumption of all departments in the works for a period of a few days. There has been an instance in which a graphical record of this quantity revealed a marked general tendency for the men

to be slow in getting their machines started for the day's work. As a result, attempts were made to remedy this fault, and the success of these efforts was measured by the increased area under the power-time curves shown by the shaded portions in Fig. 10.

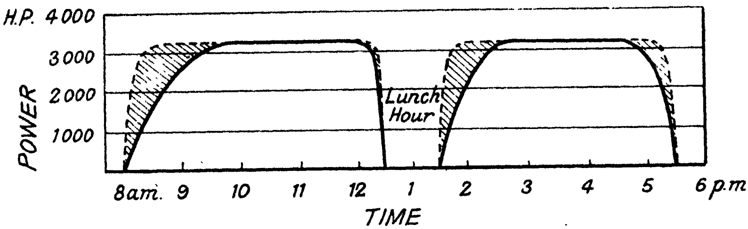


FIG. 10. POWER-TIME CURVES FOR MACHINE SHOP

MAIN FACTORY.
BAY No. 5.

Letter	No. & Size of Slates.	Date W/E.	Letter	No. & Size of Slates.	Date W/E	Letter	No. & Size of Slates	Date W/E.	Letter	No. & Size of Slates	Date W/E.
K	1. 14 x 12	6·6·31	E	3. 14 x 12	3·2·32	C	2. 14 x 12.	8·3·33			
T	1. 14 x 12	"	M	5. 16 x 12	"	D	1. 14 x 12	"			
A	3. 16 x 12	"	N	4. 14 x 12	"	E	1. 14 x 12	"			
B	2. 16 x 12	"	O	7. 14 x 12	"	H	12. 14 x 12	21·9·33			
C	3. 14 x 12	20·6·31	P	2. 16 x 12.	24·9·32	J	7. 14 x 12	"			
D	7 14 x 12	"	O	5. 16 x 12.	"	K	6. 14 x 12	"			
E	4. 14 x 12	"	S	3. 14 x 12.	"						
F	2. 14 x 12	11·10·31	T	3. 14 x 12.	31·9·32						
J	4. 14 x 12.	"	U	5. 16 x 12.	"						
K	7. 14 x 12.	"	H	2. 14 x 12	"						
L	1. 14 x 12.	"	J	4. 14 x 12	"						
M	9. 16 x 12.	25·10·31	K	4. 14 x 12.	"						
N	4. 14 x 12	"									

FIG. 11. PAGE FROM SLATE MAINTENANCE RECORD BOOK

COSTS. Repair costs of roofing, slating, and painting are kept under their separate headings in book form, as in Fig. 11, a "key" plan being also kept, on which the bays of the works are numbered horizontally and lettered vertically, making it possible to ascertain the places where the repairs are heaviest.

Allocation of Service Costs to Departments. The ideal method, of course, is to meter the services to each department, but where this is impracticable a good method which has been in operation for a number of years is illustrated in Fig. 12. The cards are made up in block form with a "flimsy" and a card. The "flimsy" goes to the Costs Office, the card being filed in the Plant Office under a card index system. The costs are filled in once a month and are based on the number of hours worked and the number of people

MONTHLY ALLOCATION SHEET. Nº 27 DEPARTMENT (BUFFERS)							MONTH ENDING 31·7·34	
							EXTRA FOR OVERTIME	TOTAL FOR OVERTIME
ELECTRICITY	LIGHT	Nº OF LAMPS. 3 - 60W 30 - 200W		AVERAGE UNITS PER HOUR 6·2		TOTAL UNITS 62	32 hours	UNITS ~~44·6~~ ·7%
	POWER	PLANT Nº	H.P.	DESCRIPTION	AVERAGE LOAD IN UNITS PER HOUR	TOTAL UNITS		
		M 8	25	Serial Nº 32592	18·648	876		
		M132	15	" " 32672	11·198	526		
			23% AIR COMPRESSOR POWER			370		UNITS 8048 2·9 %
GAS	Nº OF STOVES	TYPE		AVERAGE FT³ CONSUMED EACH PER HOUR		TOTAL FT³		CUBIC FEET.
	8	BUNSEN		1·333		501		11,194
	6	TINMENS		6		1692		·9 %
STEAM	HEATING	AREA OF SHOP 5,400 ft.²		% OF HEATING ALLOCATED. 81				1·0 %
	INDUSTRIAL	TYPE OF PLANT Degreasing Plant 2 Chemical Colanders Sawdust Tank		TOTAL % ALLOCATED.				22 %
WATER	DRINKING	% ALLOCATION ON Nº OF PEOPLE						%
	INDUSTRIAL	TYPE OF PLANT 2 Chemical Colanders ½" supplies 1½" "		APPROX. GALS. PER HOUR 202				GALLONS 63,792 1·2 %
AIR	TYPE OF PLANT Nº OF PISTOLS. 30							%
	WORK'S ENGINEERS COPY						WORK'S ENGᴿ	

Fig. 12. Costs Allocation Sheet

in each department. The estimated consumptions of the departments are based on figures taken periodically with portable meters which are inserted in the appropriate mains or pipe lines without the knowledge of the department concerned. Allocations for lighting are taken from a sliding scale, as shown in Fig. 13.

Thus if lighting starts at 4 p.m. in one department and finishes at 6 p.m., and in another department of similar size continues until 8 p.m., the percentage of the lighting bill for the latter would be double that of the shop finishing at 6 p.m. Whilst, of course, lighting-up time fluctuates, the sliding scale chart provides a very good average.

Labour Costs. The actual costs of repair work are, of course, covered by "X" orders, but so that a check can be kept on the Maintenance Department's costs, a chart is made out as shown in Fig. 14. This chart gives the number of men per section, average hours per man, and the wages costs per section, and is compared with the total production of the works. From this chart the Works

Engineer can decide as to the advisability of starting extra men or putting on a night shift during a peak period.

INSPECTION OF MACHINES AND PLANT. A systematic inspection of the equipment of the works will prevent production delays, in addition to maintaining the standard of production and reducing the cost of upkeep. The inspection should be carried out at regular intervals by means of a card system as follows. Each inspection job is typewritten on a card, and the cards filed in suitable groups.

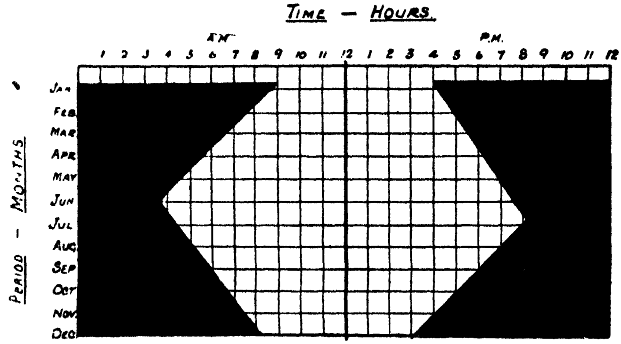


FIG. 13. DIAGRAM SHOWING AVERAGE HOURS OF LIGHT AND DARKNESS
(Summer time not allowed for)

When an inspection is due, the appropriate card is removed from the file and re-inserted in such a place that it will come out on the date of the next inspection.

Power equipment and distribution, electric motors, generators, and control equipment, belting, the condition of buildings, stairs, floor loads, fire-fighting plant, conveyers and elevators, heating apparatus, boilers, machine tools, compressed air systems, and refrigerators are the chief divisions into which the work of inspection falls. The inspectors should make full use of the cards bearing the records of the individual machines, and should take into account the information given on them when recommending the replacement of a machine.

PLANT REFERENCE. All machine tool and other catalogues are kept in glass-fronted book cases in the Plant Office, and are indexed under firms' names and cross-referenced under the product or type of machine, etc., a symbol being used for each type of product, e.g. PR.—Presses, ST.—Steam, AU.—Automatics, etc.

All leaflets should be filed alphabetically in trays under firms' names and cross-referenced in a "product" record in book form. A "loan book" should be kept and anyone borrowing a book made to sign for it, with the date loaned and the date returned: this is

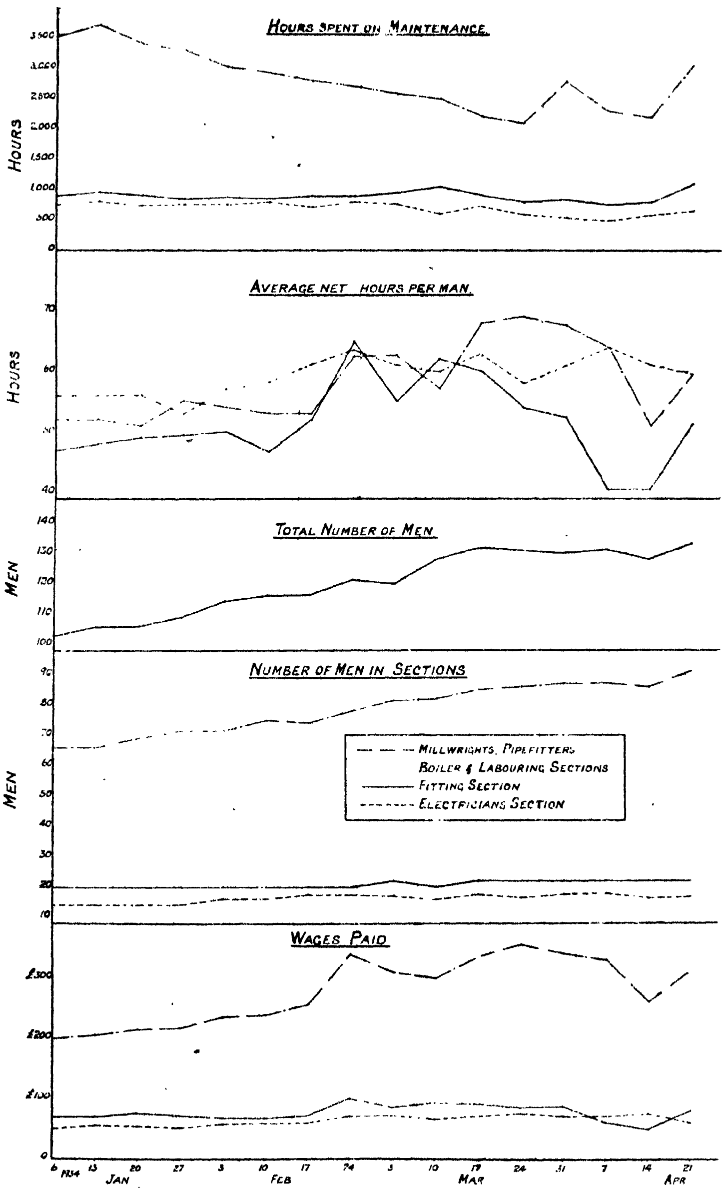


FIG. 14. CHARTS SHOWING LABOUR STATISTICS FOR A WORKS MAINTENANCE DEPARTMENT

essential, or otherwise the library of such literature would soon be depleted.

LAYOUTS AND DESIGNS. The draughtsmen in the Works Engineer's office of a large organization can usually be grouped under two headings:—

Those concerned with machine tool design and machine layouts.

Those concerned with buildings, steelwork, pipe layouts, etc.

Most works have problems peculiar to their manufactures, and the author has found that a technical reference file, as shown in Fig. 15, is very useful.

It will be seen from the illustration that it is a visible card index, and any job—other than routine work—where formulae have been needed is recorded. The formulae used are entered on a card, together with such details or modifications as have been made on the actual job. A considerable amount of time is thus saved in collecting details before starting the actual drawing. In rush periods, it enables draughtsmen not used to the class of work to get ahead without worrying their colleagues. It is surprising how many useful data—to obtain which otherwise would mean wading through numerous textbooks—can be collected over a few years.

Drafting machines of the vertical type are another essential for quick work, suitable lights being fitted to each board, as shown in Fig. 119, page 192. In an office with about six draughtsmen, the technical reference file, together with the drafting machines, is equivalent to an extra draughtsman.

FILING OF DRAWINGS. In a Plant and Maintenance Office, the types of drawings are so varied that ordinary book filing systems are not satisfactory. A very successful method, which has saved a lot of time, is a visible card index system as shown in Fig. 16. Drawings are numbered and filed under a symbol, e.g. Buildings—BL., Layouts—L., Press guards—PG., Steam—ST., etc. As an example, a drawing of an extension to a main factory may be required. From the card illustrated in Fig. 17 it will be seen that the drawing number is BL. 1-5, and the drawing will be filed in the BL. drawer under this heading.

In the case of drawings from which blue prints are taken for use in the shops, a note should be made on the individual index card, and on the drawing itself, of the number of blue prints taken from it. This is important, for when an alteration in a dimension is made, all blue prints must be called in so that the new dimension can be entered on them, and so that possible delays thus caused may be minimized. It should, therefore, be possible for the drawing office to know exactly where each print is to be found, and in a large works it may be advisable to keep a systematic record.

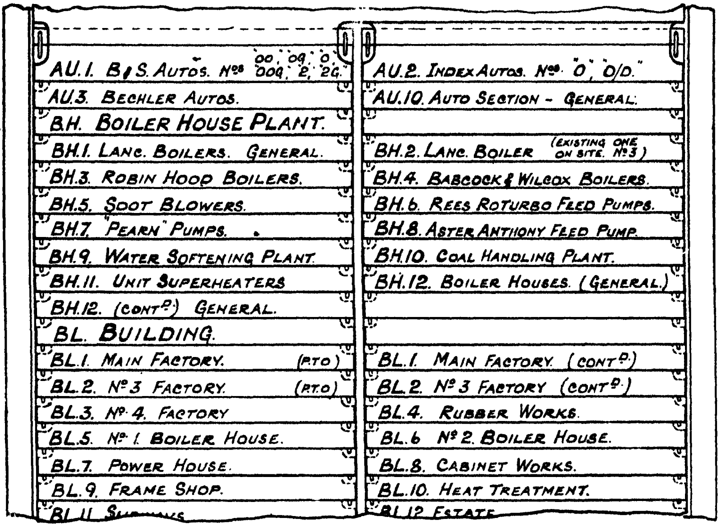
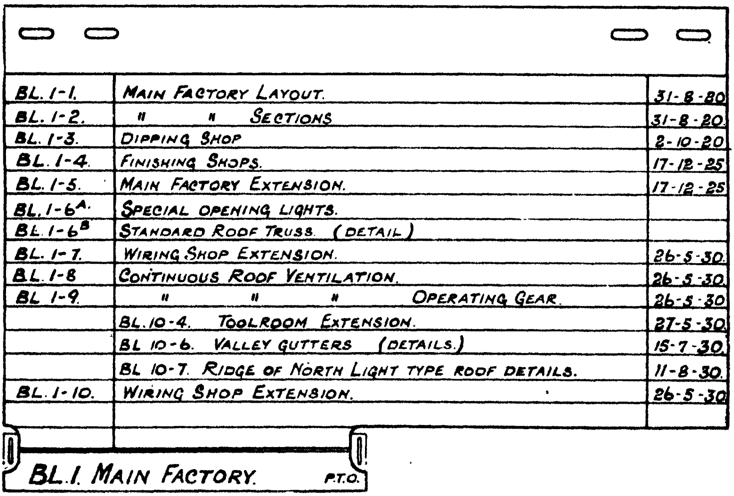


FIG. 16. DRAWING REFERENCE FILE



BL. 1-1.	MAIN FACTORY LAYOUT.	31-8-20
BL. 1-2.	" " SECTIONS	31-8-20
BL. 1-3.	DIPPING SHOP	2-10-20
BL. 1-4.	FINISHING SHOPS.	17-12-25
BL. 1-5.	MAIN FACTORY EXTENSION.	17-12-25
BL. 1-6A.	SPECIAL OPENING LIGHTS.	
BL. 1-6B	STANDARD ROOF TRUSS. (DETAIL)	
BL. 1-7.	WIRING SHOP EXTENSION.	26-5-30
BL. 1-8	CONTINUOUS ROOF VENTILATION.	26-5-30
BL. 1-9.	" " " OPERATING GEAR.	26-5-30
	BL. 10-4. TOOLROOM EXTENSION.	27-5-30
	BL. 10-6. VALLEY GUTTERS (DETAILS.)	15-7-30
	BL. 10-7. RIDGE OF NORTH LIGHT TYPE ROOF DETAILS.	11-8-30
BL. 1-10.	WIRING SHOP EXTENSION.	26-5-30

FIG. 17. INDIVIDUAL CARD FROM DRAWING REFERENCE FILE

BLUE PRINT ISSUE RECORD

No. of Drawing ....

Date	No. of Prints Supplied	Department Receiving Prints	Signature for Reception	Date of Withdrawal for Alterations	Initials of Chief Draughtsman

The form given above may be used for this purpose. It should be made certain in every case that, in the event of a new drawing of the part being made, a new blue print cannot be supplied until the old one has been returned, as it is quite likely that in any department the alteration may be such that material accidentally machined to the *old* print after the issue of the new one would be rejected as scrap, because of dimensions being increased on the new drawing.

In the case of a special blue print store being attached to each of the larger departments, a card record should be kept, a single card for each drawing being filed in order. When a print is taken from the store, a "withdrawal" card is inserted behind the card for that drawing, and removed when the print is returned.

Blue prints which are in frequent use in the shops should be preserved by mounting them on three-ply wood or on cardboard, a coat of varnish being afterwards applied to prevent damage by oil or dirt.

The compilation of a list of the materials needed for the various components on each drawing is a duty best performed by the drawing office, although it is almost entirely a clerical job. These lists, alternatively known as *specification lists* or *bills of materials*, should follow immediately after the actual drawing has been issued; they should contain full instructions as to which department should produce each part.

Every engineer knows the trouble of locating underground mains and drains, and a successful arrangement which the author has found invaluable is a large-scale plan, say to $\frac{1}{8}$ in. to the foot, which, for a works covering some 15 acres, will take up one wall of the office (approximately 17 ft. × 12 ft.). Whenever, during excavations, pipes are unearthed, they are marked on the plan; and eventually it is possible to chart all underground mains and drains.

All service mains are inserted in their distinguishing colours, e.g. red for gas, brown for compressed air, black for steam, etc., and all pipes throughout the works are painted the appropriate colours. By this means one can see at a glance what a pipe is carrying. Also, all machines are represented on the plan by celluloid-covered drawing pins, one pin being used for each machine. This plan is also very useful when change-overs are taking place, the machines being checked and the pins changed each morning during the progress of the change-overs, so as to provide a visual record of the previous day's work. It is also advisable to have plans showing the separate layouts for each service, such as steam, gas, water, etc., in the

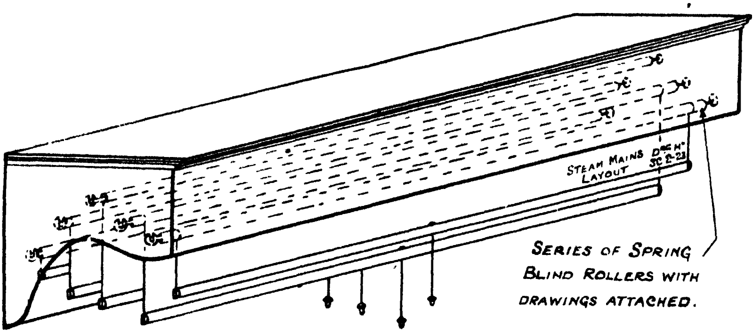


FIG. 18. METHOD OF FILING LAYOUT DRAWINGS FOR QUICK AND EASY REFERENCE

Works Engineer's office; a suitable method of filing is shown in Fig. 18.

When large electrical installations have to be carried out, it is often very useful to have some system of checking the progress of the work. One simple method is to provide the foreman or chargeman with sheets of transparent paper the same size as the sketches or blue prints actually used. The transparent paper is pinned on to the blue print, and, as each item is installed, its outline is traced on the transparent paper. Each connection is also traced as it is made. This method not only provides a continuous check, but forms an aid in the following of any complicated wiring job.

KEY REGISTER. All doors are numbered, likewise the corresponding keys, and these numbers, besides being charted on the large plan, are listed in a register, which also gives particulars of persons who are responsible for the respective keys.

SMALL LITHO PRINTS (say 13 in. × 8 in.) of a works are also very useful, especially when extensions are contemplated: they save a lot of time otherwise spent in making numerous drawings, and enable the management to sketch extensions in, and to decide on one or two schemes before actual drawings are made. Providing the

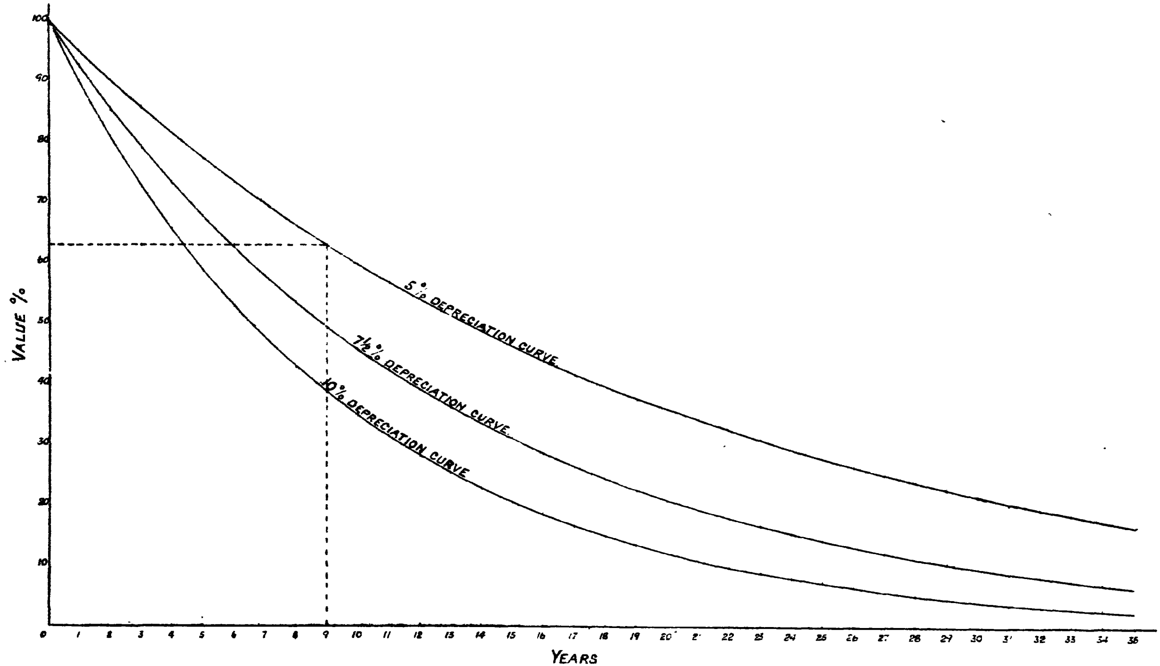


FIG. 19. DEPRECIATION CURVES

plan is sectionalized in, say, 20 ft. × 20 ft. bays, it is possible to see at a glance how much space can be allotted in different parts of the works. In a works where extensions have been more or less an annual event, over 100 of these plans, which would have entailed perhaps fifty or sixty drawings, have been used in twelve months.

Depreciation of Plant and Buildings. The working out of depreciation year by year on any particular piece of plant or building takes considerable time, and the writer has used the chart shown in Fig. 19, which gives the direct percentage of the original value for any number of years. For example, if a machine is nine years old and depreciation is taken at 5 per cent per annum, the percentage of the original value will be seen to be 63.

CHAPTER II

STEAM

BOILERS

THERE is much to be said both for the Lancashire and the water-tube types of boiler; everything depends on circumstances, e.g. the floor space available, condition of the feed water, quality of coal, type of load, and a number of other circumstances peculiar to each particular application.

The Lancashire Boiler, on account of its large capacity, is better able to deal with large variations of load, there being less danger of priming, scaling, and corrosion. As it has no small tubes, a feed

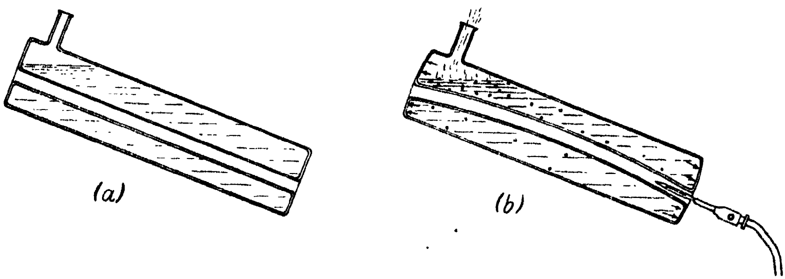


FIG. 20. GLASS DEMONSTRATION BOILER

(*a*) Boiler cold. (*b*) Heat applied. Flue expands, creating stresses both in the flue tube and on ends (boiler end plates)

water with a greater amount of impurities can be used, and also a lower grade of fireman can be employed. As with all internally fired boilers, in consequence of unequal expansion and contraction, it is subjected to straining. The glass boiler in the old laboratory of the Manchester Steam Users' Association was perhaps the best illustration of what takes place within the boiler. Fig. 20 (*a*) shows the boiler cold. In (*b*), the flue tubes, being in direct contact with the fire, become hotter than the shell, and so undergo greater expansion, thus setting up stresses other than those due to steam pressure.

The usual way to overcome this is for a section of the flue tubes to be made corrugated, or else two or three sections of the flue tube are made smaller in diameter than the others, these being arranged alternately. There is a tendency for boiler makers to reduce the length of the corrugations, more especially where high pressures are concerned. For a boiler 30 ft. long, with 250 lb. per in.^{2} working pressure, it is advisable to have 15 ft. of corrugations in each flue tube. As to the merits and demerits of the dish-end or flat-end types of boiler, whilst

there is little to choose between them, both types have the tendency to "groove," and should this happen, the dish-end boiler is at a decided disadvantage, as insurance companies will not allow the grooving to extend to such an extent in dish-end as in flat-end boilers. The former are entirely dependent on the camber for strength, whereas the latter have gusset stays. It thus happens that in flat-end boilers, grooving around the furnace openings or adjacent to the heel of the shell angle is frequently allowed to break through before the insurance company insists on repairs, but they will not allow grooving to this extent on the dish-end type, and there is always the possibility that they may ask for the end plates to be replaced, a difficult and expensive operation. Whilst the insurance companies prefer the flat-end type of boiler, a rather general trouble, especially with high-pressure types, is experienced in getting the rivets, adjacent to the toe bolts on the lower gusset stays, to hold against the pressure. For this reason the boiler manufacturers favour the dish-end type. A boiler insurance company should always be consulted before ordering a new boiler, as they can be very helpful. For a small cost they will also examine during manufacture.

Flue sizes for a 30 ft. × 8 ft. boiler can be seen from Fig. 21 which illustrates a typical Lancashire boiler of the flat-end type.

Water-tube Boilers. The great point in favour of the water-tube boiler is the saving in floor space as compared with the Lancashire boilers (the space required being about halved for the same evaporation). They are quick-steaming and, being of the externally fired type, they are not subjected to the same stresses as the Lancashire type. A higher degree of efficiency can be maintained, and greater strides seem to have been made in the design of suitable furnaces than in the internally fired boiler; this enables lower-grade fuels to be used.

Fig. 22 shows a standard Babcock & Wilcox water-tube boiler with chain-grate stoker. It may be mentioned here that the modern chain-grate stoker gives greater latitude for burning poor quality coal with smokeless combustion.

Fig. 23 shows a vertical tube boiler constructed by Messrs. John Thompson for a large woollen factory. It is complete with superheater, water-cooled walls, economizer, forced-draught type chain-grate stoker, and induced draught equipment.

With water-tube boilers greater care must be taken to keep the feed water free from impurities and oil. The saline matter in suspension in the boiler water should never be allowed to reach a greater total density than 500 grains per gal., in fact it is now generally recognized that the boiler water should not contain more than 50-75 grains per gal. of caustic alkalinity.

Priming, i.e. the carrying over of water mechanically mixed with the steam, is to be guarded against. Not only does it carry away heat without producing useful work, but it may have serious effects

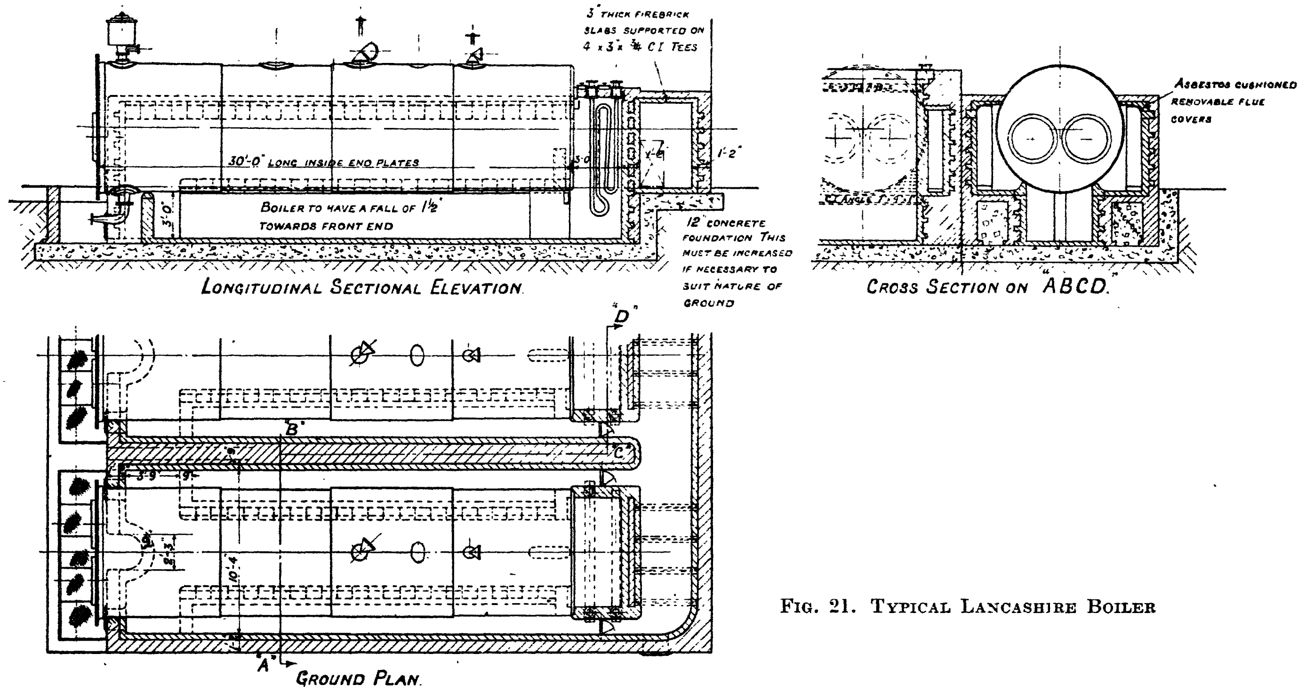


FIG. 21. TYPICAL LANCASHIRE BOILER

on the turbine or engine. Priming may be due to impurities in the water, or to the water level being too high when forcing a boiler.

Bulging, "Hogging," or Sagging of Tubes. The main troubles to look for are bulging, "hogging" (upward bending), or sagging of the tubes, due to overheating; also pitting caused through accumulation of scale or a small patch of oil.

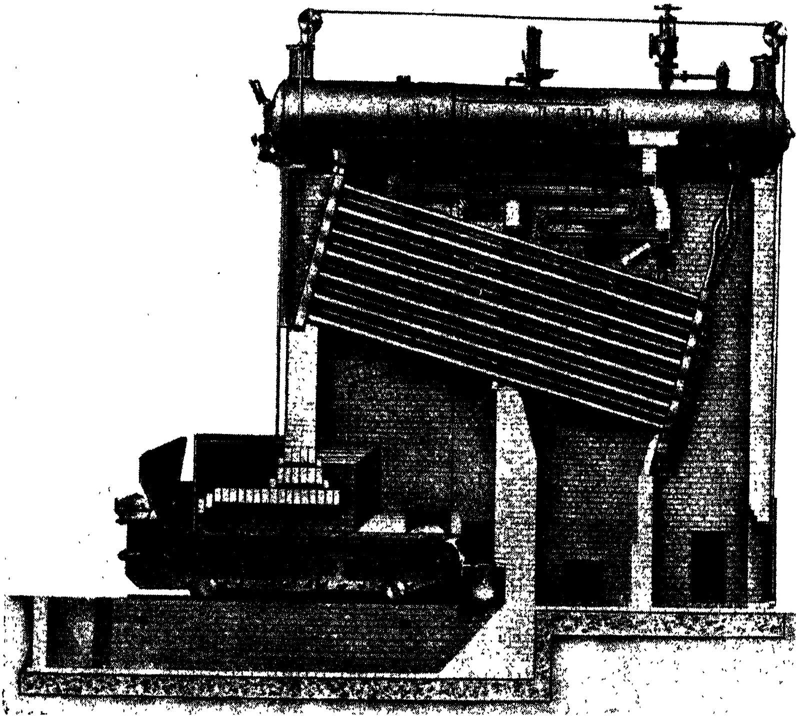


FIG. 22. BABCOCK & WILCOX BOILER WITH CHAIN-GRATE STOKER
(Babcock & Wilcox)

Inspection of the bottom rows of tubes should be made every four to six months, especially if the boiler has to be fired for long periods. One or two tubes in the two bottom rows should be sufficient to give a good idea of the general condition. In Babcock boilers, remove the hand-hole caps at each end of the tube and insert a hand lamp in the rear end; this will give a good view of the tube. If scale is present, clean out the whole of the tubes with a steel brush, or scaling tool if necessary. The latter may be steam,

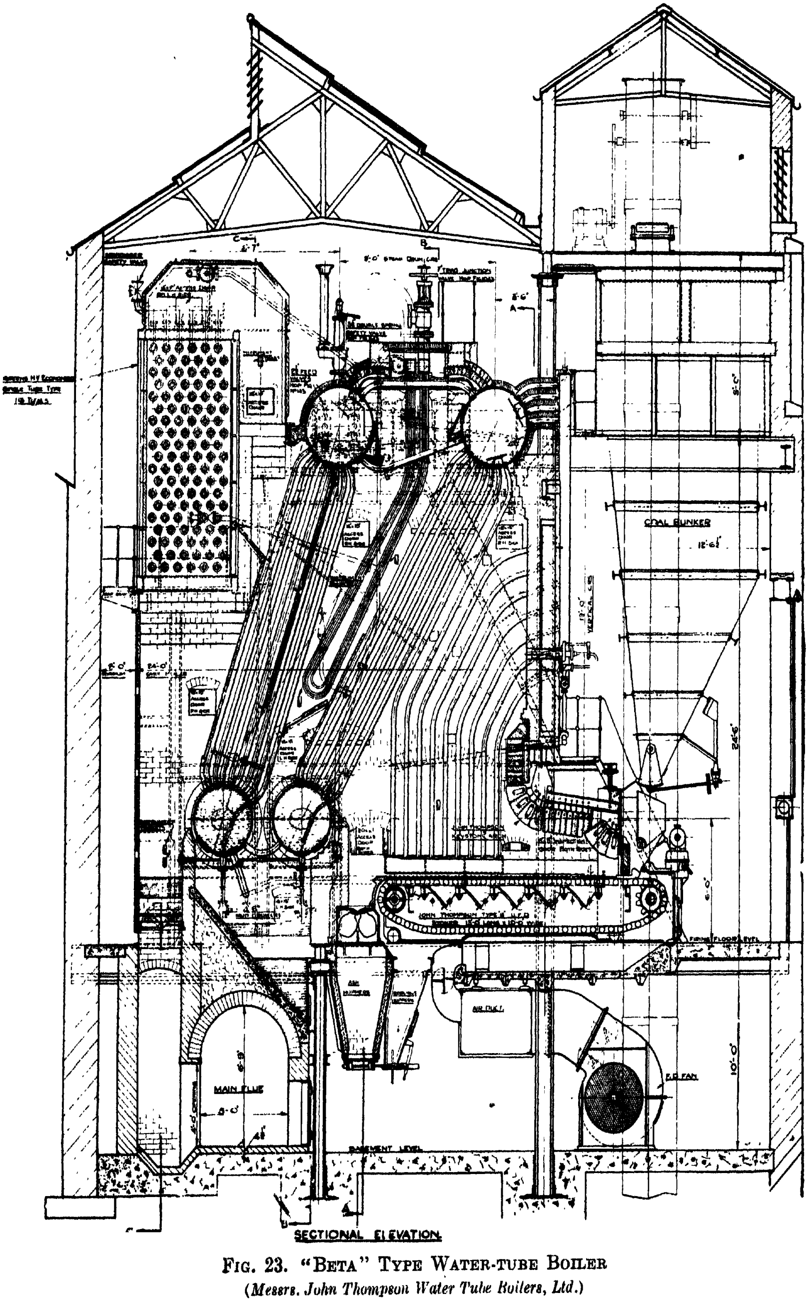


Fig. 23. "Beta" Type Water-tube Boiler
(Messrs. John Thompson Water Tube Boilers, Ltd.)

air, water, or electrically driven. Whichever type is used, the application is very simple and efficient. Fig. 24 shows the type made by Messrs. Babcock & Wilcox. When measuring for hogged or sagging tubes, a piece of string should be stretched from one

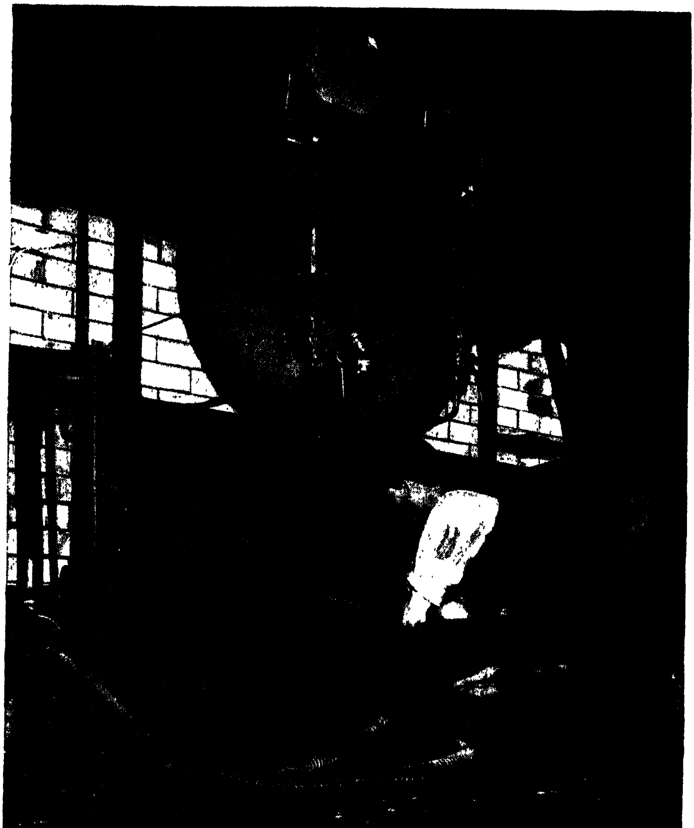


FIG. 24. METHOD OF OPERATING TURBINE TUBE CLEANER
(*Babcock & Wilcox*)

extreme end of the tube to the other; any deviation up to $1\frac{1}{4}$ in. is considered permissible.

In a Stirling type boiler the tubes terminate in the steam and water drums (as opposed to the section headers of a Babcock & Wilcox boiler), and so there are no hand-hole caps. Access to the tube ends has to be obtained through manholes in the drums. The ends of the tubes are sharply curved, so that the hand-lamp method

will enable only the ends of the tubes to be sighted, and the string method of detecting hogging cannot be applied.

Scoring of Tubes. The position of soot-blower jets should be checked periodically. If the jets get slightly out of place, abrasive action due to the grits picked up with the jets of steam will wear away the sides of the tubes. Superheater tubes should be carefully watched, as in order to get the necessary heating surface for high superheat, they are very closely spaced, and so displacement of the soot-blower jets by even ½ in. may cause excessive wear. The author once had to replace some half-dozen tubes, due to slight movement of the brickwork pulling the soot-blower out of position.

Nesting of ash in the tubes should also be carefully watched, as this, apart from reducing the efficiency of the boiler, will create an undesirably high circulation in the clean steam tubes, due to the tendency for water to use only those tubes where circulation is good.

Air Leaks. Air leaks are due to badly fitting dampers and cracks in the brickwork. These should be given immediate attention, as they will greatly reduce the efficiency of either Lancashire or water-tube boilers.

Whilst it would seem from the troubles enumerated above that the water-tube boiler is likely to give more trouble than the Lancashire type, this is not actually the case if ordinary precautions are taken to keep the boiler in proper condition.

For numerous industrial loads, the ideal combination is Lancashire and water-tube boilers. The Lancashire type, due to its reserve and capacity, has an accumulator effect and this, coupled with the rapid firing of the water-tube boiler, makes a most satisfactory plant where working pressures for process steam must be kept constant concurrently with a great variation in the steam requirements.

Whereas the Lancashire boiler has to be heated up slowly, the water-tube boiler can be forced and steam raised very quickly without undue strain on the boiler drums and tubes.

General Care of Boiler Plant. A detailed list of instructions to boiler men should be posted in every boiler house. The following are the main items:—

Part of Boiler to be Cleaned	Action to be Taken	Remarks (How often, etc.)
Boiler blowdown .	—	Once per shift
Economizer . .	Open draining valve	Once per shift
Soot-blower . .	Must be thoroughly drained before opening	Once per shift minimum
Water-gauges .	—	Must be kept clean and blown down once per shift
Safety valves. .	Lifted by hand	Once each day
Ashing out . .	**To suit particular plant requirements**	

To these items can be added the times and hours of each shift and any other instructions to suit the particular plant. All repairs and inspections should be entered on the boiler log sheet.

Maintenance of Meters and Gauges. All gauges and recording meters should be periodically checked and overhauled, to ensure accurate readings at all times repairs and overhauls being entered in a log book (Fig. 25). A good practice is to keep a number of

DEPARTMENT.	RUBBER WORKS.		GAUGE Nº 33.
RANGE.	0 TO 120 LB./IN.²	MAKER. SIR W.H. BAILEY.	
DATE.	TESTED	REMARKS.	SIG:
28·10·26	O.K. AT 60 LB.	BUT 10 LBS. SLOW BEFORE & AFTER.	[illegible]
"		SENT TO MAKERS.	"
18·11·26	O.K.	AFTER REPAIRS BY MAKER.	"
6·7·28	ERRATIC READINGS.		[illegible]
"		SENT TO MAKERS FOR OVERHAUL.	"
14·8·28		RETURNED FROM MAKERS.	"
"	INCLINED TO BE	SLOW UP TO 30 LB./IN.² O.K. AT 100 LB./IN.²	
"		SEND INTO STORES AS SPARE	"

FIG. 25. PAGE FROM GAUGE LOG BOOK

spare parts, and also several complete mechanisms. When any particular gauge is due for overhaul, its mechanism is removed and a spare one installed in its place. The dial and pointer are then attached, and finally a check for accuracy is made.

To check recording thermometers while they are in operation, a simple method is to insert an auxiliary pocket in the main, as close as possible to the pocket for the instrument. The pocket is kept full of oil, and a glass thermometer is inserted whenever a check reading on the regular instrument is required.

Great care should be taken to ensure that pressure gauges are placed so that vibration is the minimum possible, otherwise the

maintenance expenses will be considerable, especially in the case of costly high-pressure instruments. In some cases it is possible for the gauges to be mounted on cork, or separated from the panel by cork insulation, which will damp out vibration and prevent unsteady action.

Steam flow meters must be watched, if fitted with mercury columns, in order to keep the mercury from being contaminated by impurities in the steam. A suitable filter for the steam should be fitted after blowing out the connecting steam pipes. A solution of 1 part of nitric acid in 3 parts of distilled water can be used for cleaning the mercury, which should afterwards be washed in distilled water and dried by heating it in an open dish to 230° F.

Fractures of water gauge glasses may be caused by the rubber rings blowing out. This can sometimes be prevented by dropping a fibre washer, about $\frac{1}{16}$ in. thick and $\frac{3}{4}$ in. inside diameter, on to the rubber ring, so as to separate the ring from the gauge nut. The washer should fit the gauge glass closely, so as to prevent the rubber ring from being squeezed out through the clearance between the gauge glass and the hole in the nut. In some cases, plaster of Paris is used as a retaining material for gauge glasses, care being taken to allow time for it to set before the boiler is put in steam. When time does not permit, tin-foil may be employed. It should be rolled into a long strip, stiff and slightly flattened, and should be rammed gently home with a small screwdriver.

Economizers. To assist in keeping down steam-raising costs, an economizer should be included in the boiler installation. With Lancashire boilers, a saving of 15 to 20 per cent in fuel costs can be effected by this means; with well-designed water-tube boilers, owing to the lower flue-gas temperatures (about 500° C.), the saving amounts only to about 6 to 8 per cent. Care must be taken to see that corrosive action does not take place in the economizer tubes; if water enters the economizer at less than 100° F., there is always a likelihood of this occurring. The tubes may be made of steel or cast iron. Two of the best-known economizers are Green's, and the Babcock & Wilcox type. In the former the tubes are of cast iron, and in the latter they are of steel. A new rotary economizer (the Simmons Patent Economizer), which is now being made in this country, gives a remarkable efficiency.

Air Heaters. Where low-grade fuels are used, the efficiency of combustion can be increased by pre-heating the air necessary for combustion. To achieve higher efficiencies in boiler plants it is necessary to reduce the temperature of exit gases to a minimum. The air heater can be installed either before or after the economizer. It is not possible to quote exact figures for savings, as everything depends on the type of plant and the temperature of the exit gases on entering the air-heater.

Superheaters. As the superheater is usually an integral part of

the boiler equipment, there is no necessity here to include formulae for the heating surface required for a given superheat. It is usual when buying a boiler to state the evaporation and the superheat required. Mention may be made here of the saving derived by using superheated steam, especially when driving turbines or reciprocating engines, as the nearer to a perfect gas the steam becomes, the greater the efficiency of the prime mover. The average percentage saving in steam consumption due to superheat can be taken as 1 to 10, i.e. each 10° F. of superheat = 1 per cent saving in steam consumption.

Boiler Formulae

The first essential is to calculate the *actual evaporation* (W) which may be written:—

$$W = \frac{\text{Weight of water evaporated}}{\text{Weight of coal consumed over the same period}}$$

It must be realized that it is impracticable, on account of the varying classes of coal, differing feed water temperatures, and unequal steam requirements at varying pressures, to compare one boiler with another, and it is, therefore, necessary that a "standard" should be observed, in order that tests for efficiency may be compared on a common basis.

For this purpose it is first necessary to assume as conditions (*a*) a coal without ash, (*b*) feed water at 212° F., and (*c*) steam delivered at atmospheric pressure. In the first place, therefore, a factor is required to represent the weight of water which would be evaporated per lb. of coal, if all evaporation were to take place at 212° F. This *factor of evaporation* (F) as it is called, is calculated as follows:—

Suppose that W lb. of steam is evaporated per lb. of coal.
,, ,, H is the total heat per lb. of saturated steam.
,, ,, H_1 is the total heat per lb. of superheated steam.
,, ,, L is the latent heat of steam.
,, ,, Q is the heat per lb. of feed water entering the boiler.

Then W(H − Q) = Heat transferred from fuel to steam.

Now imagine a theoretically perfect boiler (efficiency 100 per cent) to serve as a standard of comparison. This ideal boiler is fed with water at 212° F., evaporating it at atmospheric pressure and forming dry saturated steam (also at 212° F.). Suppose that the W(H − Q) units of heat referred to above are supplied to the ideal boiler, then the quantity of steam evaporated would be

$$W(H - Q)/L \text{ or } W(H - Q)/970{\cdot}4 \text{ lb.}$$

The figure 970·4 refers to the latent heat of steam at 212° F., in B.Th.U. per lb. This amount, W(H − Q)/970·4, is described as the *equivalent evaporation from and at* 212° F., and may be regarded as the product of the actual evaporation per lb. of fuel and the factor of evaporation F.

Thus $\qquad WF = W(H - Q)/970{\cdot}4.$

Therefore $\qquad F = (H - Q)/970{\cdot}4.$

The ("liquid") heat per lb. of feed, Q, is numerically equal to $(t - 32)$ B.Th.U. per lb., where t is the feed temperature, the specific heat of water being taken as unity.

Thus $$F = \frac{H - (t - 32)}{970{\cdot}4}$$

Secondly, it is necessary to account for the varying qualities of coal used, and a basis of 10 000 B.Th.U. per lb. being recognized as standard, the above formulae may be expanded as follows:—

$F = \dfrac{H - (t - 32)}{970{\cdot}4} \times \dfrac{10\,000}{C}$ where C is the calorific value of the fuel in B.Th.U. per lb.

This may be written:—

$$\text{Equivalent evaporation} = WF \times \frac{10\,000}{\text{Calorific value of fuel}}$$
$$= WF \times 10\,000/C.$$

Boiler Efficiency. In order to arrive at the boiler efficiency η_B, we have to consider the heat transmitted in the boiler per lb. of coal, ignoring superheaters and economizers. This item, expressed in B.Th.U. per lb. of coal =

Actual evaporation × (total heat per lb. of saturated steam − total heat of feed water entering the boiler),

which may be written—

Heat transmitted $= W \times H - (t - 32)$ in terms of B.Th.U.

Taking into account the calorific value of the fuel, the heat units transmitted to the boiler expressed as a percentage of the available units of heat per lb. of coal $= \dfrac{\text{Heat transmitted}}{\text{Calorific value}} \times 100$

which again may be written—

$$\eta_B = \frac{\text{Heat transmitted}}{C} \times 100 \text{ per cent.}$$

Superheater Efficiency. The heat units actually used for the purpose of superheating, per lb. of coal consumed, will be—

$$\text{Actual evaporation} \times \left[\begin{pmatrix}\text{Total heat per}\\ \text{lb. of super-}\\ \text{heated steam}\end{pmatrix} - \begin{pmatrix}\text{Total heat per}\\ \text{lb. of satura-}\\ \text{ted steam}\end{pmatrix}\right]$$
$$= W \times (H_1 - H) \text{ in terms of B.Th.U.,}$$

or, expressed as a percentage as in the case of the boiler efficiency equation—

$$\text{Heat units} = \frac{\text{Gain of total heat due to superheater}}{C} \times 100 \text{ per cent.}$$

Economizer Efficiency. The heat units transmitted per lb. of coal consumed

$$= \text{Actual evaporation} \times \begin{bmatrix} \text{Temperature difference of} \\ \text{feed water between inlet} \\ \text{and outlet of economizer} \end{bmatrix}$$

$$= W \times (t_1 - t) \text{ in terms of B.Th.U.,}$$

or expressed as a percentage of the available heat per lb. of coal

$$= \frac{\text{Gain of total heat of steam due to economizer}}{C} \times 100 \text{ per cent.}$$

Combined Efficiency. By adding together the heat quantities of boilers, superheaters, and economizers we shall, therefore, obtain the *combined efficiency* in terms of B.Th.U. per lb. of coal consumed: alternatively, by adding together the percentage efficiencies of the three units we shall obtain the combined efficiency expressed as a percentage of the total available heat units in 1 lb. of coal.

These formulae may be combined as—

$$\text{Combined efficiency} = \frac{W \times [H_1 - (t - 32)]}{C} \times 100 \text{ per cent,}$$

or, the combined efficiency calculated from the equivalent evaporation from and at 212° F. per 10 000 B.Th.U. in the coal will be—

$$\frac{WF[H_1 - (t - 32)]}{10\,000} \times 100 \text{ per cent.}$$

For convenient reference, these formulae are summarized below.

Actual Evaporation $= \dfrac{\text{Weight of water evaporated}}{\text{Weight of coal consumed over the same period}}$.

Equivalent Evaporation from and at 212° F. $= WF \times \dfrac{10\,000}{C}$.

Evaporation Factor $= \dfrac{H - (t - 32)}{970{\cdot}4} = \dfrac{H - Q}{970{\cdot}4}$.

Boiler Efficiency $= \dfrac{W \times [H - (t_1 - 32)]}{C} \times 100$ per cent,

or, $\dfrac{\text{Heat transmitted}}{C} \times 100$ per cent.

Gain in Total Heat due to Superheater $= W \times (H_1 - H)$ B.Th.U. per lb. of coal consumed, or,

$$\text{Efficiency} = \frac{W \times (H_1 - H)}{C} \times 100 \text{ per cent.}$$

Economizer Gain in Total Heat $= W \times (t_1 - t)$ B.Th.U. per lb. of coal consumed, or,

$$\text{Efficiency} = \frac{W \times (t_1 - t)}{C} \times 100 \text{ per cent.}$$

Combined Efficiency = Boiler Efficiency + Superheater Efficiency + Economizer Efficiency; or,

$$\frac{W \times [H_1 - (t - 32)]}{C} \times 100 \text{ per cent.}$$

Combined Efficiency (based on Equivalent Evaporation)

$$= \frac{WF[H_1 - (t - 32)]}{10\,000} \times 100 \text{ per cent}$$

where

W = Actual evaporation per lb. of water per lb. of coal.

F = Factor of evaporation.

H = Total heat per lb. of saturated steam.

H_1 = Total heat per lb. of superheated steam.

C = Calorific value of fuel.

L = 970·4 = Latent heat per lb. of saturated steam.

$(t_1 - 32)$* = Heat per lb. of feed water entering the boiler at temperature t_1.

$(t - 32)$* = Q = Heat per lb. of feed water entering the economizer at temperature t.

Whilst the foregoing gives a simple method of arriving at the thermal efficiency of whole, or part, of the boiler plant, which is sufficiently good for use in the ordinary commercial running of a works boiler plant, more comprehensive trials should be made with a new installation.

These should follow the *Standard Code for Comprehensive Boiler Trials* as laid down by the Heat Engine Trials Committee before the Institution of Civil Engineers (1927). The Report is published by William Clowes & Sons, Ltd.,† and, as its name implies, it includes all heat engine trials, a fact which makes it invaluable to the Works Engineer.

* This is, of course, simply a numerical equality, applying in this case to 1 lb. of water.

† At 5s.

FEED WATER

Wherever possible the condensate from prime movers and industrial plant should be returned to the feed water tank. This condensate reduces the cost of feed water treatment and also the heating of feed water; but what is most important, the formation of scale is greatly reduced. Care must be taken to see that oil does not get into the condensate.

Softening. The apparatus for softening the make-up water is the most important part of the plant, for scale, apart from the waste of

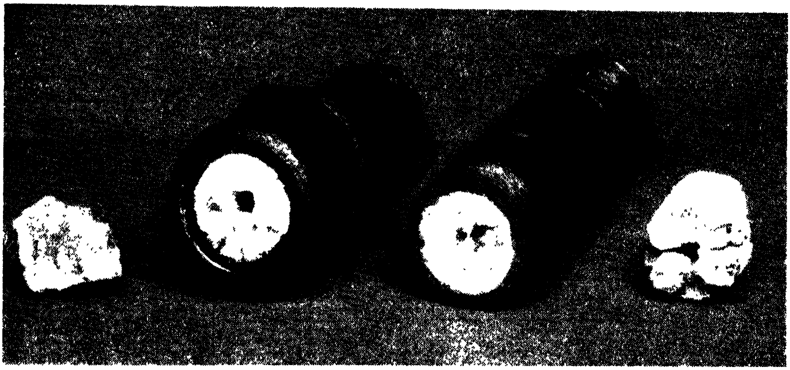


FIG. 26. EXAMPLES OF SCALE IN PIPES

fuel it causes through its insulation effect between the water and boiler shell or tubes, is also the cause of most of the troubles and repairs that are met with. When starting a new plant or utilizing another source of water, the chemist should be called in to make a full analysis and advise as to the method of treatment to adopt. Fig. 26 shows scale formation in calorifier delivery pipes using untreated water.

The classification of water is by *degrees of hardness*, which may be given in parts per 100 000 or in grains per gallon: the latter is the usual or British method, and is sometimes known as the *Clark scale of hardness*. It is always advisable when comparing waters to check which measurements are implied.

Hardness is classified under two headings, *permanent* and *temporary*.

TEMPORARY HARDNESS is due to the presence of carbonates of lime and magnesia, which are held in solution by carbonic acid. If this water is boiled, the carbonic acid gas, which is combined with the carbonates to form bicarbonates, is driven off, and the carbonates which are insoluble are precipitated.

PERMANENT HARDNESS. This may be taken as the solids left in

suspension after the carbonic acid has been driven off; it is due to the sulphates, nitrates, and chlorides of lime, which are not precipitated by boiling.

Softeners. Water softeners can be classed under two headings, *Precipitation* and the *Base Exchange.*

THE PRECIPITATION OR SODA AND LIME METHOD is the one most in use. The lime combines with the carbonic acid, forming carbonate of lime, which is precipitated with the carbonates, which were first in the form of bicarbonates. The soda ash converts the dissolved sulphates of lime and magnesia into carbonates, leaving sulphate of soda which is soluble and does not form scale. Fig. 27 shows a typical lime-soda softener.

The hard water from the inlet pipe alternately fills one or other of the two compartments in the measuring apparatus, which, when full, tips over, emptying into the softening compartment below. As each compartment fills up and tips, a valve is operated in the bottom of the chemical solution container placed alongside the measuring apparatus, allowing a predetermined quantity of the solution to pass into the softening compartment, there mixing with the hard water. The water then travels to the settling chamber, passing through wood-wool filter beds to the softened water reservoir, the level of which controls the hard water inlet to the delivery pipe by means of a ball valve. At the opposite end of the apparatus is a circular mixer for thoroughly mixing the soda ash and lime, which is thence pumped up once more to the chemical solution container.

BASIC EXCHANGE METHOD. In this method the feed water is filtered through a granular base-exchange bed, usually known by a trade name, such as "Permutit"; this has the property of giving up its sodium base to the water that is passed through it, in exchange for any calcium or magnesium present in the water. The beds have to be reactivated from time to time with a weak solution of common salt. Base exchange plants should not be used for boiler feed purposes without first taking expert advice, as with many waters the process is unsuitable owing to the concentration of soda salts which takes place in the boiler.

Coagulation. Where river or canal waters (and even some well waters) are used, marl, silica, organic waste, vegetable colours, etc., may be present in such minute form as to be on the border line between solution and suspension; these are known as *colloidal impurities.* They should be dealt with by using a coagulant such as sulphate of alumina. This reacts on the calcium carbonate to form aluminium hydrate. These flocculent precipitates have great coagulating power, i.e. the formation of an insoluble gelatinous mass. The extra cost of using coagulation plant above that of ordinary softening is not heavy, being about 0·125d. per 1 000 lb. of steam generated.

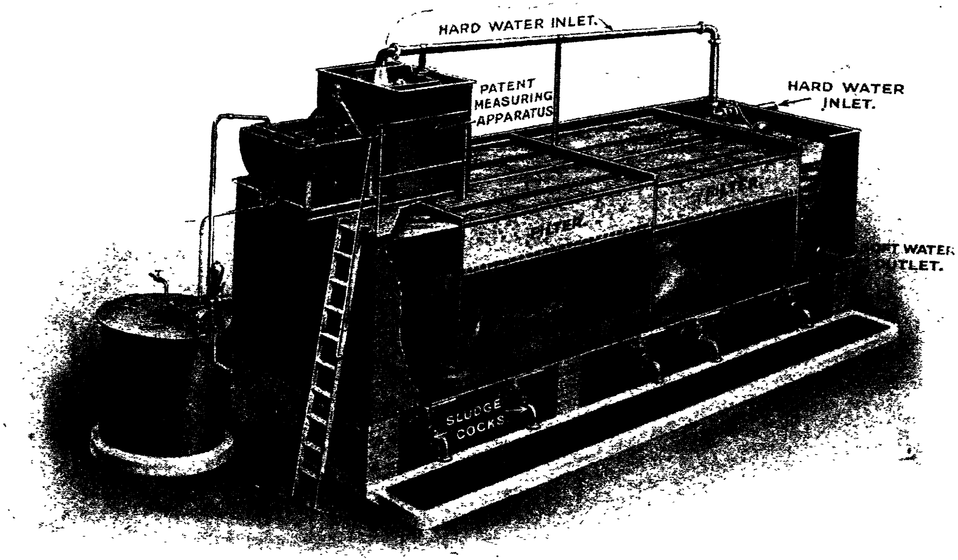


FIG. 27. PRECIPITATION WATER SOFTENER
(*Babcock & Wilcox*)

The Testing of Feed Water. When supplying a water softener, the manufacturers usually include a complete water-testing outfit, which comprises a supply of standard soap solution; alkalinity indicators (phenolphthalein and methyl orange); standard acid (sulphuric) and the necessary burettes; dropping bottles for alkalinity indicators; 100 cm.^{3} measure; shaking bottle of about 150 cm.^{3} capacity; beakers, stirring rods, etc.

METHOD OF TESTING FOR HARDNESS. Measure out 70 cm.^{3} of the water to be tested, then run out the soap solution from a burette, 1 cm.^{3} at a time, shaking vigorously after each addition until a permanent lather is maintained for five minutes. The number of cubic centimetres indicated on the burette will be the degrees of hardness of the water sample in grains of calcium carbonate per gallon.

ALKALINITY TEST. Again measure out 70 cm.^{3} of the water sample and transfer to a beaker, adding about four drops of phenolphthalein. If free alkalinity is present, the sample will become a purple colour. The standard sulphuric acid is now added drop by drop from the burette whilst stirring the sample until the purple colour disappears. The number of cubic centimetres of acid which have been added are taken as the degrees of phenolphthalein alkalinity, or the free alkalinity.

It is now necessary to take the bicarbonate alkalinity, which has no effect upon the phenolphthalein.

Take another 70 cm.^{3} of the water sample and transfer to a beaker as before; then add ten drops of methyl orange. (The original sample also has ten drops added to it to serve as a comparison for colour.) Sulphuric acid is then added as in the previous test, a cubic centimetre at a time until the colour shows the slightest tinge of pink, which can be readily noted by comparison with the previous sample. The amount of acid, in cubic centimetres, that has been poured in must then be added to that added during the previous test; the sum of these quantities will give the total alkalinity.

Condensate. As mentioned earlier, the whole of the condensate should, wherever possible, be used for boiler feed purposes, as the condensed steam is practically pure, and also by so doing, the heat remaining in it is conserved. Treated water need only then be used for make-up, and so a saving is effected by reducing the quantity to be treated. Even when very little make-up is necessary, the feed as a whole must be carefully watched, as it may contain considerable quantities of dissolved gases, oxygen and carbon dioxide, which have been absorbed from the atmosphere. From these carbonic acid is formed which will attack the boiler plates and tubes. These gases, therefore, must be eliminated, and it may be necessary to install a de-aerator for this purpose.

The aeration of the water can be considerably reduced if due care

is taken to see that the water in the feed tank is not agitated—say due to delivery from a ball valve—since where agitation is permitted bubbles will be formed and carried below the water surface, where the gases they contain become dissolved in the feed water.

Blowdowns. These are usually hand-operated, and the period that elapses between each blowing down and the quantity of scum to be blown down is dependent on the rate of concentration of the soluble salts; so that occasionally it may be found necessary to fit

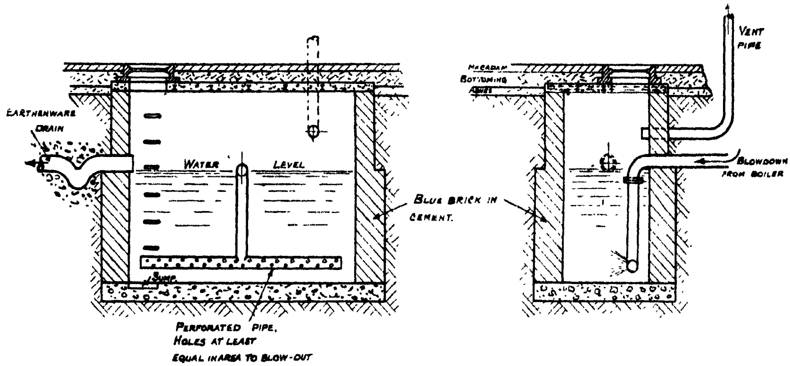


FIG. 28. CONSTRUCTION OF BOILER BLOWDOWN EXPANSION CHAMBER

a continuous blowdown. Whilst every care must be taken to keep down the concentration, it must be remembered that excessive blowing down will waste useful heat and reasonably pure water, although with the continuous blowdown, the greater part of the heat can be saved by the installation of a heat exchanger which is connected to the blowdown pipe system, thereby transferring useful heat to the feed water. Where the boiler blowdown has to pass to the works drains, some form of expansion chamber is necessary between the boiler blowdown pipe and the drains. A typical chamber is shown in Fig. 28. As mentioned earlier in this chapter, the concentration of the boiler water should never be allowed to exceed 500 grains per gal., and Messrs. Babcock & Wilcox recommend the following conditions for feed water and boiler water—

Feed Water Conditions

Dissolved oxygen, less than 1 cm.^{3} per litre.
Chlorine, not greater than 0·3 grains per gal.
Alkalinity: definitely caustic, but not more than 0·5 grains per gal.

Boiler Water Conditions

Caustic alkalinity, not greater than 50 grains per gal., total solids 500 grains per gal.

Chloride not greater than 30 grains per gal.

Hardness as near zero as possible.

Oil, no indication or slightest trace; and the recommended ratio of sodium sulphate to alkalinity (i.e. total alkalinity expressed as sodium carbonate) should be 1 : 1 up to 150 lb. per in.^{2}, 2 : 1 from 150 to 200 lb. per in.^{2}, and over 200 lb. per in.^{2}, 3 : 1.

NOTE. An important paper on this subject was recently presented and discussed before the Institution of Mechanical Engineers. See *Proc. I. Mech. E.*, 1935, vol. 129, page 7.

Wastage in Idle Boilers. When boilers are laid off for a few months, say during the summer period, care must be taken to ensure that internal corrosion does not take place. There is a greater tendency for internal corrosion to take place in an idle boiler than when it is in commission.

When a boiler is left standing half full of softened water over long periods, the internal corrosion which takes place is due to the dissolved oxygen and carbon dioxide in that water.

There are two methods of overcoming this; one is to fill the boiler completely with water, taking care to exclude all the air, the other is to empty the boiler completely.

The latter method is the better, for if the boiler should be filled up with water the plates will be cold and moisture will condense on the external surfaces, thus causing external corrosion. Should the boiler be completely isolated during part of the winter, the water may freeze, thereby straining the joints. It will be realized, therefore, that the best method is to empty completely all idle boilers when they are left for long periods, ensuring that the boiler is left completely dry by, say, lighting a small fire in the flue tubes or by putting a brazier inside the boiler.

BOILER FEED PUMPS

Reciprocating Pumps. In most small and medium-sized industrial boiler houses, one still sees the reciprocating donkey pump. With this type, unless the water is metered before entering the pump—say over a weir, as with the Lea Recorder—there is little possibility, due to the pulsating flow which is experienced, of getting an accurate measurement of the amount of water pumped to the boilers. Unless great care has been taken in the layout of the pipework and in the design of the orifices, the steam consumption is likely to be high compared with that of the turbine-driven pump, and the floor space required is also usually greater than that required for the latter type. Also it is not usually desirable to use the exhaust steam from the donkey pump for feed-heating purposes, owing to the possibility of its contamination with oil.

The first cost of the donkey pump, however, is lower; and the upkeep costs are less than with the turbo feed pump. If the reciprocating type of pump is installed, care must be taken to see that

the valves are of maximum area and minimum lift. When installing the pump, it should be placed as near the boiler as possible, and, if the feed water is hot, the suction pipe should be much larger than the inlet, with a minimum lift. An air vessel of suitable dimensions should be installed, its function being similar to that of the engine flywheel; the size of the air vessel should be five to six times the displacement of one stroke of the pump. If possible the air chamber should be fitted on a vertical pipe with a tee connection to the boilers: where this is impracticable, a small deflector should be inserted in the tee on the horizontal main to ensure that the water is forced against the air cushion and does not pass straight through without taking due advantage of this cushion. With all reciprocating pumps the wear on the boiler check valves and springs is obviously heavier than with the turbine pump, but if the foregoing points are watched, this should not be excessive.

The Centrifugal Pump is, of course, ideal for a steady feed; it is compact, and whilst its first cost is perhaps three times that of the reciprocating pump, its advantages are that the wear and tear on check valves is reduced to a minimum, the adjustment of boiler feed is much finer than with the reciprocating pump, and due to the absence of pulsations a much more accurate measurement of the water passing through can be obtained.

In larger plants the electric motor-driven pump is used with great success, but even with a variable-speed motor a certain amount of throttling of the water delivery valve is necessary. The combination of a motor-driven pump to take a steady load with a small turbine-driven pump to take the fluctuations of load above the normal, constitutes an arrangement that is, perhaps, ideal. For large installations a combined turbo-electric pump such as that developed by Messrs. G. and J. Weir, Ltd., is suitable.

FIRING

Automatic Combustion Control. To-day automatic combustion control has been so improved that not only is it being installed in large power plants, but it is also being utilized more and more in industrial plants. It is recognized that with automatic control increased boiler efficiency, prevention of smoke, and better control of a group of boilers can be maintained, and the saving is such that even with the smaller industrial plants of, say, two or three medium-sized boilers it may be worth serious consideration.

As its name implies, it governs completely the process of combustion in accordance with the steam demand, without manual operation. There are two main systems, the electrical and the hydraulically operated control. The latter, owing to its simplicity, is mostly used on the smaller plants. The Kent electrical system is shown in Fig. 29.

The aim of the system is to keep the pressure constant in the

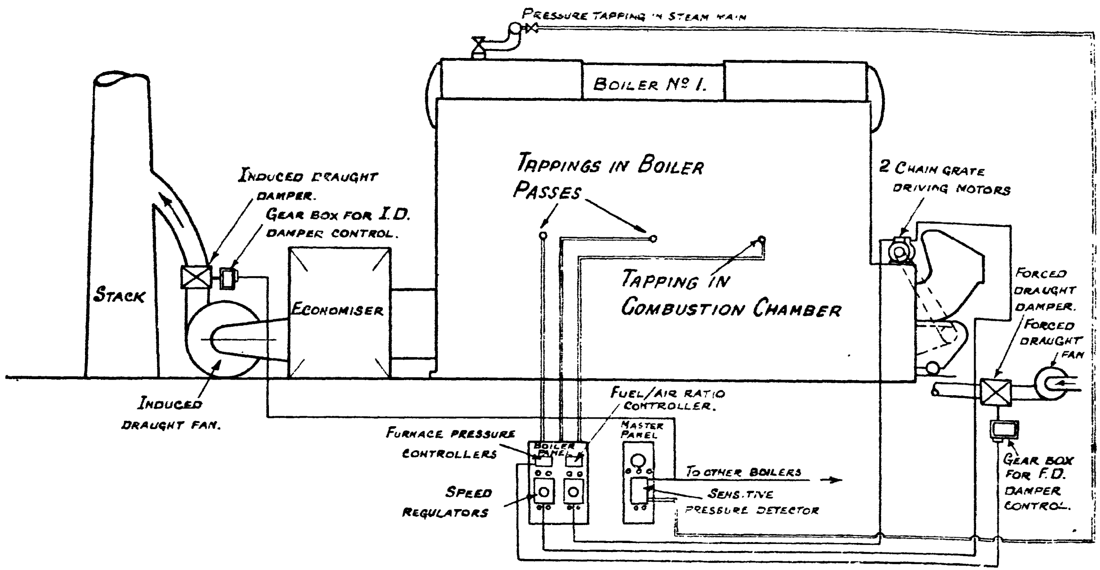


Fig. 29. Kent's Electrical System of Automatic Combustion Control

receiver or steam main. Any pressure change in the latter will operate through a master controller and so alter the induced draught of every boiler in that group, until the pressure returns to its steady predetermined value. Naturally, such an alteration in induced draught would upset the furnace pressure, but this is provided for by an automatic readjustment of the forced draught by independent

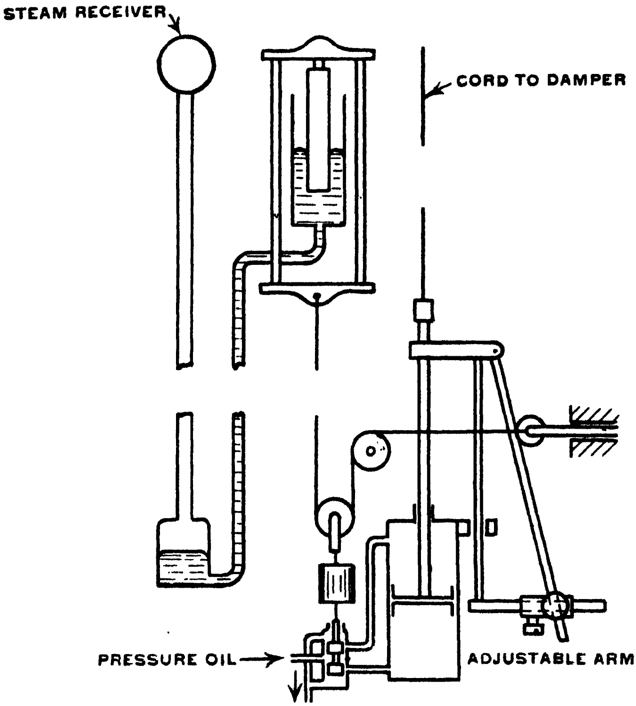


FIG. 30. HYDRAULIC BOILER CONTROL SYSTEM
(*Proc. I.Mech.E.*)

controllers. Mechanical means are provided for measuring the new air flow through the furnace, and for adjusting the fuel flow (on the chain grate) to suit. The induced and forced draught fans are adjusted by controlling, through field rheostats, the speeds of shunt-wound direct-current motors. This is arranged by having a single motor, which runs continuously and drives two shafts in opposite directions. Magnetic clutches are used to clamp the shafts to the two sides of a differential gear connected to another shaft which raises or lowers the sliding arm of the rheostat. For lower air flows,

adjustment of the dampers is made. The fuel/air ratio for each load on the boiler is governed in the first place by a cam in the fuel/air ratio controller. This ratio can be altered by a push button either in the control room or on the boiler front. The chief features of the system are: the control of each function in sequence, instead of all functions simultaneously; the steps taken to avoid "hunting" of

FIG. 31. MASTER PANEL FOR AUTOMATIC COMBUSTION CONTROL

the controls; and the facility for overriding the signals sent out by the master controller (by the use of the push buttons already mentioned) without switching off. Adjustment of individual controls on each boiler front can also be made without switching off.

A diagram illustrating one of the hydraulic systems is given in Fig. 30. A pressure drop in the steam main or receiver causes the movement of a float which is supported by a column of mercury. The mercury is arranged to balance the normal steam pressure.

By means of an adjustable follow-up mechanism, any movement of the float is made to operate a pilot valve. This causes the power-operated piston, which is connected to the induced draught damper, to rise; the amount which it rises depends on the amount which the mercury falls. The sloping bar attached to the crosshead of this piston can be adjusted, as regards inclination, to suit a given fall of the mercury. One mercury column can be made to control several induced draught dampers, and can thus be applied to a group of boilers. In each boiler the furnace pressure is kept constant, or made to follow every position of the induced draught damper, by a regulator adjusted to suit that particular boiler: the forced draught damper is also controlled by this regulator. Provision is also made for controlling the speed of the mechanical stoker by making it depend on the position of the induced draught damper. This is effected by a sensitive valve and an adjustable mechanism which makes allowance for variations in the chimney draught and furnace pressure. There is, however, no exact means of fixing the fuel/air ratio.

Fig. 31 shows the control panel for a hydraulic system.

Coal-handling Plant. With the general use of mechanical stokers, the mechanical handling of coal even in small factories is being more commonly adopted, but even to-day it is possible to visit plants with two or three boilers where the coal is still being dumped in the boiler house. It is only necessary to consider the saving on a simple elevator and bunker to see that the labour costs can be considerably reduced. Every layout has to be considered on its merits, but even so the manufacturers of coal-handling equipment can often put forward a money-saving proposal in connection with boilers which, at the outset, are hand-fired.

Destructors. Wherever possible, the heat from shop scrap and rubbish should be utilized for steam raising. Where a cabinet works or wood mill forms a part of a works the sawdust and wood chips should be taken direct from the machines to the boiler grate. If the wood refuse is not sufficient for the boiler, coal can be used as a make-up. Fig. 32, which is self-explanatory, shows a typical arrangement which has proved satisfactory.

For shop rubbish a destructor with a waste-heat boiler should give good results. A Heenan & Froude installation with waste-heat boiler incorporated is shown in Fig. 33. This installation is designed to give about 1 200 lb. of steam per hour.

Waste-heat Boilers. Boilers designed for the utilization of waste heat fall into two classes: (*a*) those making use of the heat discharged from various industrial furnaces, e.g. blast furnaces and open-heath steel furnaces, coke ovens, reverberatory furnaces, brick and cement kilns, etc.: and (*b*) those dependent on the heat in the exhaust gases of internal combustion engines. In class (*a*) anything from 25 to 80 per cent of the heat in the fuel is discharged

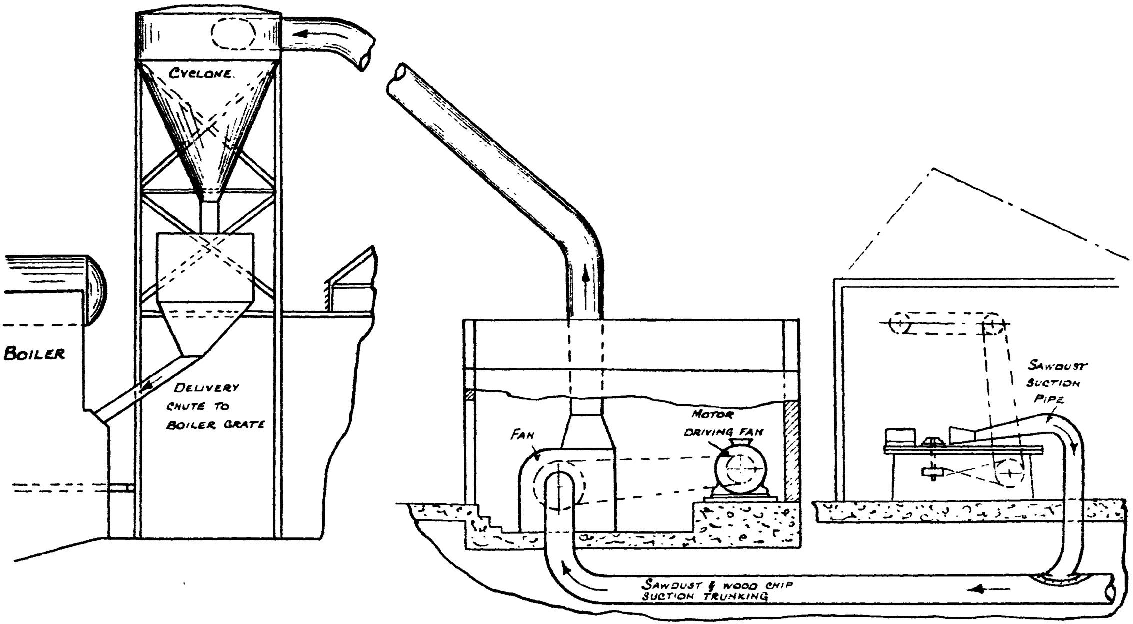


FIG. 32. SYSTEM FOR REMOVING SAWDUST AND CHIPS FROM WOODWORKING MACHINES TO BOILER AND GRATE

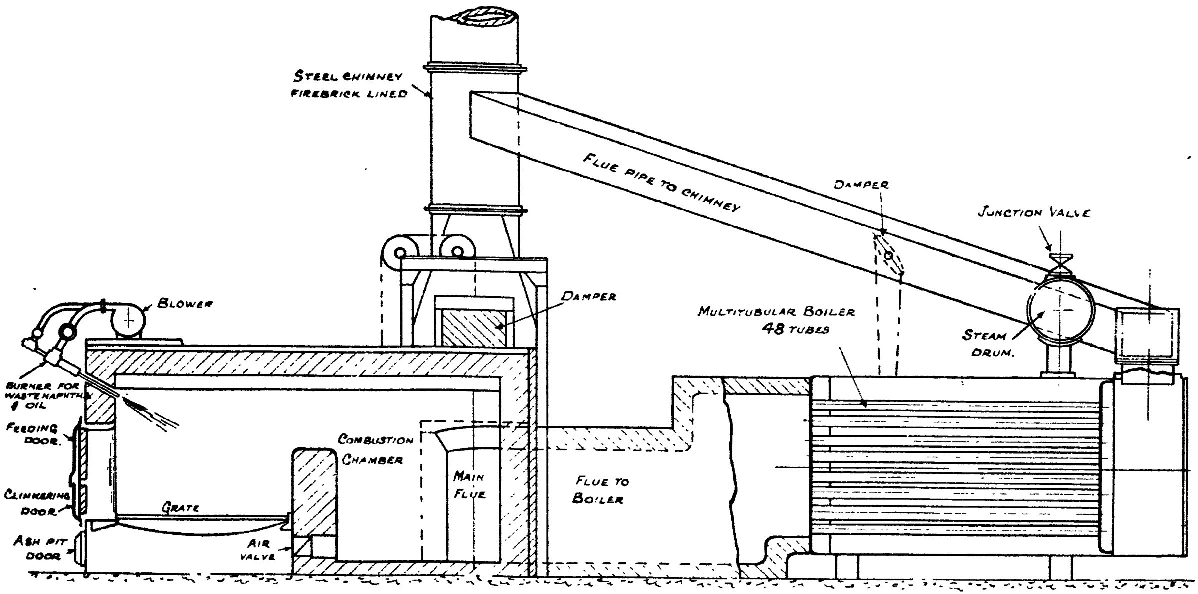


FIG. 33. DIAGRAMMATIC LAYOUT OF HEENAN & FROUDE DESTRUCTOR AND WASTE-HEAT BOILER

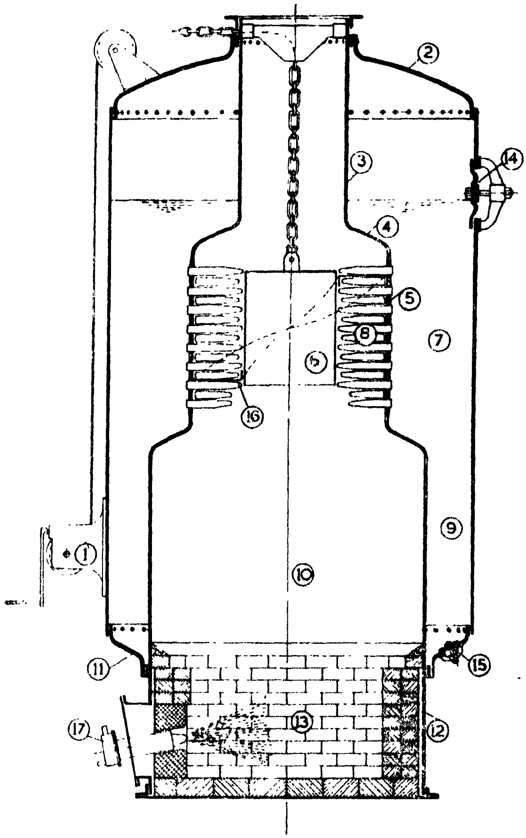


FIG. 34. THIMBLE-TUBE OIL-FIRED BOILER

1. Control to deflector
2. Dished upper crown
3. Flue plate welded to 4
4. Inner crown welded to 5
5. Thick tube plate
6. Deflector of heat-resisting steel
7. Space around tube nest for access
8. Multiple rows of thimble tubes
9. Water space around furnace
10. Furnace
11. Dished lower crown
12. Support for boiler and furnace plate
13. Brickwork
14. Manhole
15. Mudhole
16. Spiral directional plates
17. Oil burner

(*Spanner Boilers, Ltd.*)

to waste, and the success in recapturing this heat by a waste-heat boiler will depend largely on the initial temperature of the gases: it is this factor which determines the proportions of the boiler. Long cement kilns may discharge gases at 1 000° F. and the heat transfer by radiation is small. The waste-heat boiler must, therefore, provide for a high velocity of gases and a considerable length of travel. The flue gas temperature for a melting furnace may exceed 2 000° F., and the radiation will be high, so that the design of the boiler will be on the lines of the direct-fired type. Care must be taken to ensure that the installing of a waste-heat boiler will not lower the performance of the primary furnace from which it gets its heat. To provide a sufficiently high velocity through the waste-heat boiler, and to overcome the rather high friction drop through it, the draught will probably have to be increased by mechanical means.

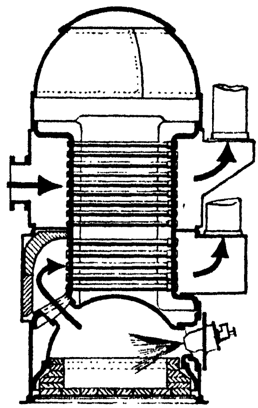


FIG. 35. COMPOSITE BOILER

The arrows refer to the directions of the gas flows, the upper two denoting the course of the "waste-heat" gas and the lower two showing the path of the gases from the oil-fired furnace. (*Cochran & Co., Annan, Ltd.*)

Type (*b*) will have perhaps 70 per cent of the heat theoretically available in the fuel for circulation.

There are two varieties: (1) that depending on exhaust gases alone for the source of heat; (2) that which receives exhaust gases, but has in addition an oil-fired furnace as a supplement. The latter is known as the *composite* type. The steam is generated either on the principle of the "thimble-tube" boiler, originated by the late Thomas Clarkson, M.I.Mech.E., or by a system of numerous short cross-tubes, with baffles arranged so that the exhaust gases pass through the lower banks first, rising to flow in reverse direction through the upper banks. In the thimble-tube system (Fig. 34), the exhaust gases flow upwards among the thimbles, and are sometimes prevented from flowing in too direct a path through the centre of the boiler by fitting a central spindle which carries helical deflector plates. Composite boilers are useful where the Diesel engines do not work at constant speed, for when the engines are slowed down, the steam output can be maintained by the oil-fired furnace. They are made in various sizes, generating from 1 200 to 3 000 lb. of steam per hour (Fig. 35).

Furnaces. To deal with the different types of grates would require more space than is possible in this book. The following can be taken as a fair guide as to the grate area—

Lancashire boiler: 15 to 25 lb. of coal per ft.^{2} of grate.

Water-tube boiler: 20 to 35 lb. of coal per ft.^{2} of grate.

Water-tube boiler, pulverized-fuel fired: $\left\{ \begin{array}{l} 0{\cdot}7 \text{ to } 0{\cdot}9 \text{ ft.}^3 \\ \text{of combustion chamber per lb. of fuel.} \end{array} \right.$

Chimneys. Depending on the efficiency and the type of boiler and grate, each lb. of coal requires from 17 lb. to 24 lb. of air, and even more where there is to be an excess of air above that required for combustion. Therefore, when calculating the size of chimneys, 24 lb. of air to 1 lb. of coal is usually taken as a basis.

To find the draught D of a chimney, in inches water gauge

$$D = H\left(\frac{7{\cdot}6}{T_1} - \frac{7{\cdot}9}{T_2}\right)$$

To find the height H of a chimney in feet

$$H = \frac{D}{7{\cdot}6/T_1 - 7{\cdot}9/T_2}$$

where T_1 = Absolute temperature of outside air in ° F.

T_2 = Absolute temperature of column of gases in the chimney in ° F.

Grit Arresters are dealt with in Chapter VI.

BOILER INSPECTIONS AND TESTS

Every facility should be given to the boiler insurance company's surveyor when he carries out his periodic inspections, remembering that whilst the Factories Act calls for this inspection and report, actually he is responsible to you and the general public for the safety of your boilers. Every engineer must therefore realize that it is in his own interest to report all leaks, however slight, to the surveyor and to give him every help by removing lagging and brickwork at seams when necessary.

Insurance companies usually ask for a hydraulic test if a boiler is over 10 years old, the test pressure being $1\frac{1}{2}$ times the blowing-off pressure of the safety valve.

HIGH-PRESSURE STEAM

The Generation of Power from Back-pressure and Pass-out Engines and Turbines. When considering new boiler plant, careful thought should be given to the saving effected by the generation of high-pressure steam (especially where low-pressure steam is required for industrial purposes). By using a turbine or back-pressure engine coupled to a generator or alternator, cheap power is generated, while the turbine or back-pressure engine acts as a reducing valve. Considering first the fundamental principles, it will be seen from the heat diagram in Fig. 36 that it requires 250 B.Th.U. to heat 1 lb. of ice to melting point, and a further 150 B.Th.U. to complete the change from ice to water. If we add a further 160 B.Th.U., the

water reaches boiling point or 212° F. A further 970 B.Th.U. must then be added before all the water is changed to steam.

From the above facts, it will be clear that once the necessary B.Th.U. have been expended in generating the steam, any extra heat added can be utilized in useful work. As an example: the total heat of 1 lb. of steam at 245 lb. per in.² gauge is 1 211 B.Th.U., whilst for 25 lb. gauge it is 1 172 B.Th.U., a difference of 39 B.Th.U. If we take the same pressures at 200° F. superheat, the

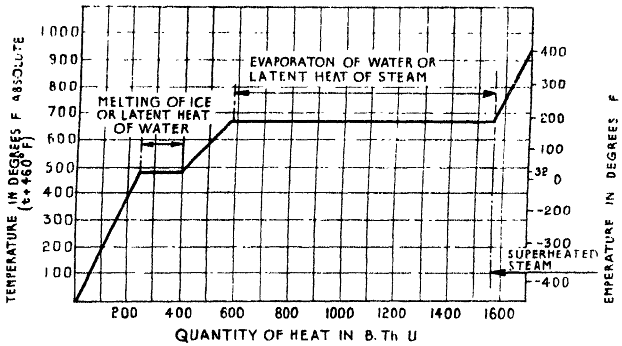


FIG. 36. HEAT REQUIRED TO CHANGE WATER INTO ITS VARIOUS STATES

total heat becomes 1 330 B.Th.U. and 1 273 B.Th.U. respectively, and it is evident that for 57 extra B.Th.U. the boiler pressure can be increased from 25 lb. to 245 lb. per in.² Consider, therefore, the conditions when high-pressure steam is passed through a back-pressure turbine or engine coupled to a generator or alternator, exhausting into the industrial or process-steam main at 25 lb. If the set has a steam consumption of 37 lb. per kW. and the overall boiler efficiency is 80 per cent, then, for every 37 lb. of industrial steam used it is possible to generate 1 kW. at an extra coal consumption of only 6·2 per cent.

Exhaust Turbines. This type is designed to exploit the fact that a greater efficiency is obtainable by using a turbine for expanding steam from the low-pressure stage of a reciprocating engine than by arranging for the final expansion to take place in an additional stage added to the reciprocating engine. Exhaust turbines are suitable for works in which the exhaust from several reciprocating engines, working intermittently, is available. The exhaust steam, instead of passing to the atmosphere, is sent through a turbine to a condenser. The variations in the supply of steam, which in turn depends on the number of reciprocating engines at work at any given moment, renders the employment of a steam accumulator necessary (Figs. 44 and 45).

Back-pressure Turbines. These turbines do not exhaust to condensers, but expand the steam delivered to them down to the pressure required for process steam. They are suitable for works where steam at high pressure is required for power plant, and also steam at low pressure for process work. A turbine of this type thus acts as a reducing valve between the high-pressure and low-pressure steam. Notable economies are possible, since the high-pressure steam, in expanding in the turbine to the pressure of the process steam, can be used to make the turbine drive an alternator, thus providing useful electrical power.

Pass-out Turbines. In this type (Fig. 37) high-pressure steam is delivered to the turbine, in which it expands down to the process steam pressure. The turbine consists of a high-pressure and a low-pressure part. The turbine chamber, in the high-pressure part, is in communication both with the low-pressure part and with the process steam main, between which and the low-pressure part an oil-operated regulator is fitted. When there is no demand for process steam, the pressure in the main increases, actuating the regulator, and allowing a greater amount of steam to pass to the condenser, by way of the low-pressure part of the turbine. An increase in demand for process steam causes a fall in pressure in the main, and closes the regulator, in order to reduce the amount passing to the condenser. When no process steam is required, the turbine receives high-pressure steam and exhausts straight to the condenser. A small amount of steam is admitted to the lower stages, to reduce the effects of vacuum at the condenser end—e.g. temperature rise caused by the churning of the steam in the casing at that end. Where the required electrical load to be carried is so great that the quantity of steam passing through the turbine is in excess of the requirements for low-pressure steam, or where there is a large variation in the low-pressure industrial steam load, the pass-out turbine is more suitable than the straight back-pressure turbine.

A section of such a turbine is shown in Fig. 37. As mentioned above, the turbine is divided into high-pressure and low-pressure sections. The "industrial" or process steam is passed out through the first stage, the extra steam required for the electrical load being guided through the regulating valves (shown directly above the pass-out steam branch on the drawing) into the low-pressure end, where it is expanded, eventually entering the condenser. The whole or part of the steam can be passed through to the condenser, thus giving a very elastic arrangement.

Mixed-pressure Turbines. Normally these turbines work as exhaust turbines, but they are provided with an arrangement for introducing high-pressure steam to the high-pressure end of the turbine at times when an extra demand is made; or when the supply of exhaust steam entirely fails, so that the turbine can be run as a high-pressure machine exhausting to the condenser. Conversely, if

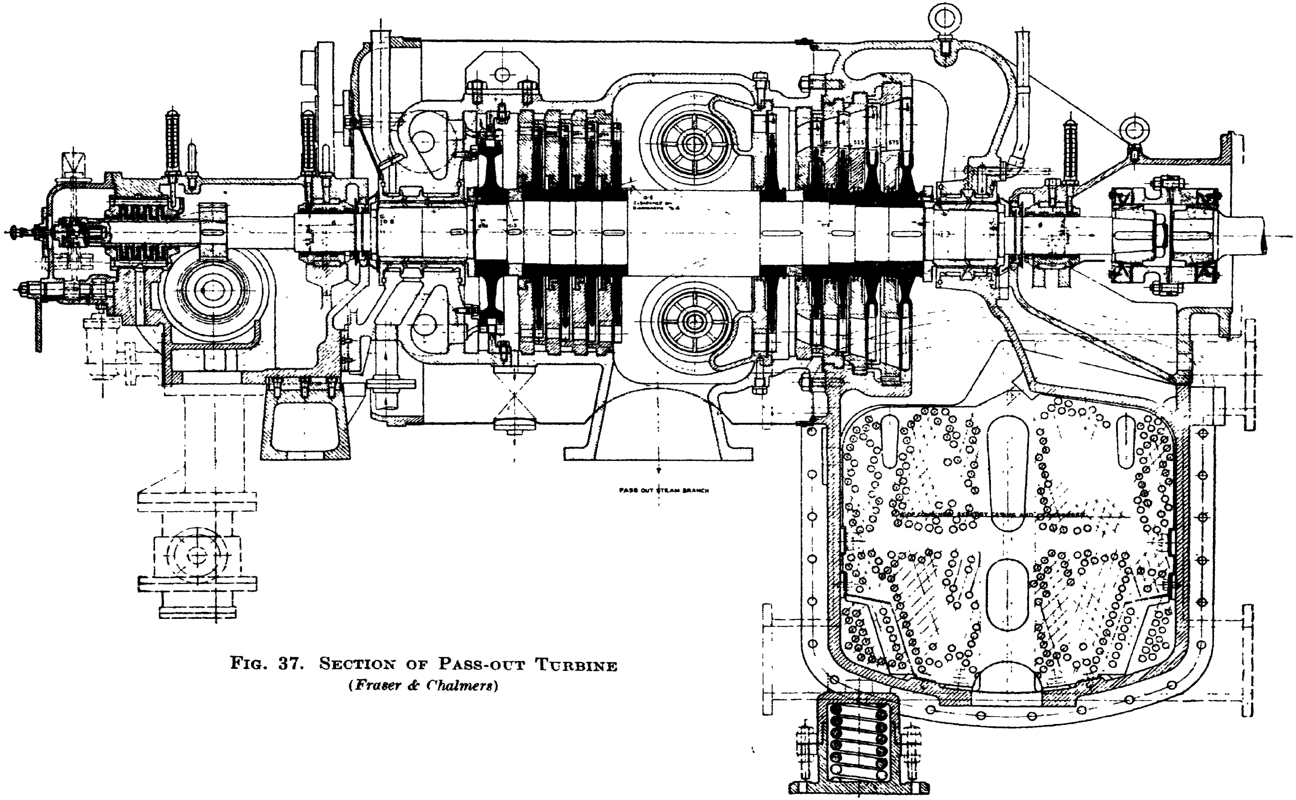


FIG. 37. SECTION OF PASS-OUT TURBINE
(*Fraser & Chalmers*)

POWER HOUSE

Week ending.........

DAY	LOAD IN kW TIME OF AND			STEAM CONSUMPTION				MAXIMUM kVA	Steam Press. & Temp		P.F.	Lb. OF STEAM PER kWh.	TOTAL HOURS RUN	TOTAL kWh	REMARKS
				TIME OF AND		FLOW METER READING AT	TOTAL								
	Highest	Lowest	Average	Highest	Lowest	Start & Stop			INLET	ONLET					
Mon.															
Tues.															
Wed.															
Thur.															
Fri.															
Sat.															
Sun.															

Total KWh's taken on Set.	Total kWh taken from Corp^n Mains	Cleaning. Inspection & Repairs
Lb. of Steam per kWh.	P.F. on Corp^n Supply	
Total Hours Run.	kVA of Max. Demand	
Total lb. of Steam consumed.	% of Load taken on Set.	
Cost per kWh.	Cost per kWh from Corp^n Supply	

Works Engineers Office ENGINEER.......... Power House

FIG. 38. RECORD LOG FOR BACK-PRESSURE TURBINE SETS

the supply of exhaust steam is sufficiently large, no high-pressure steam is required to supplement the exhaust steam.

A suitable record log for back-pressure sets is shown in Fig. 38.

Turbo-alternators. The turbine can be of the back-pressure or pass-out type. When part of the electrical supply is already taken from an external source, the ordinary back-pressure type is the more economical, as it is possible to arrange the alternator as a supplement to the external supply, so that the whole of the low-pressure steam delivered to the turbo-alternator can ordinarily be utilized. If there is more low-pressure steam than can thus be used, e.g. during peak loads on the high-pressure mains, the set can be arranged to blow to atmosphere. On the other hand, if more low-pressure steam is required than that needed for the electrical load at the moment, this extra steam can be bypassed through an Arca regulator to the low-pressure main.

Fig. 39 shows a typical heat balance diagram for a back-pressure turbo-alternator set, from which it will be noted that the thermal efficiency is 66·3 per cent, which shows that the high condenser losses are eliminated. This heat is converted into useful work.

Figs. 40 and 41 show respectively a diagram and a general view of a G.E.C.-Fraser & Chalmers turbo-alternator set arranged on this system.

On the power panels in Fig. 41 will be observed the handwheels which operate rotary links for changing over from the set to corporation supply or vice versa in a few seconds. This set has given very good results over a number of years.

Back-pressure and Pass-out Engines. The turbine is most economical when exhausting to a low back pressure, but where a high back pressure is required, the back-pressure reciprocating engine is superior.

The first cost is higher and greater floor space is required, but the greater efficiency makes the back-pressure reciprocating engine worthy of consideration.

An example of a back-pressure engine is shown in Fig. 42. Naturally the boiler installation for the live steam must carry a relatively high pressure, so that the pass-out steam may also be at a sufficient pressure above the atmosphere. Considerably more power is available if the live steam is superheated, and condensation in the process mains is also reduced. It must be remembered that even if the engine exhausted at, say, 50 lb. per in.^{2} gauge pressure, the exhaust steam would only contain about 3 per cent more heat than atmospheric steam. In the interests of economy, therefore, every effort should be made to keep the exhaust or pass-out pressure as low as possible, but at the same time a low exhaust pressure means a low steam velocity through the process mains, so the best compromise between these opposing factors must be made.

Where it is essential for the exhaust steam for process work to be

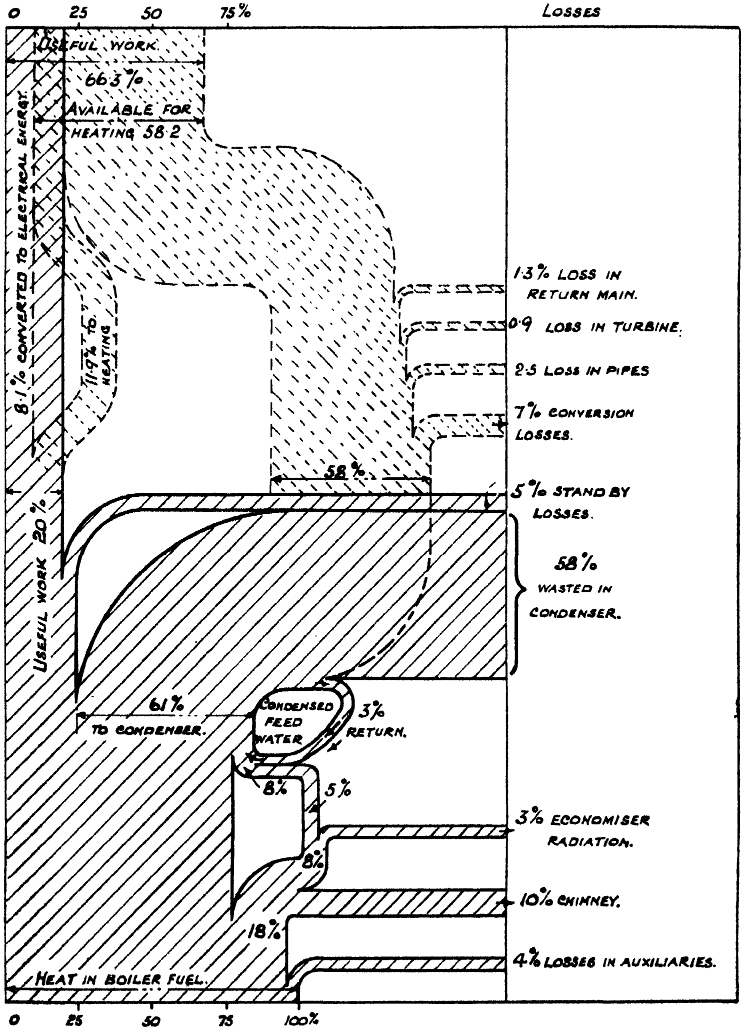


FIG. 39. HEAT LOSSES IN STEAM POWER PLANT

Losses under usual conditions shown in full line
Saving by using exhaust steam shown in dotted line

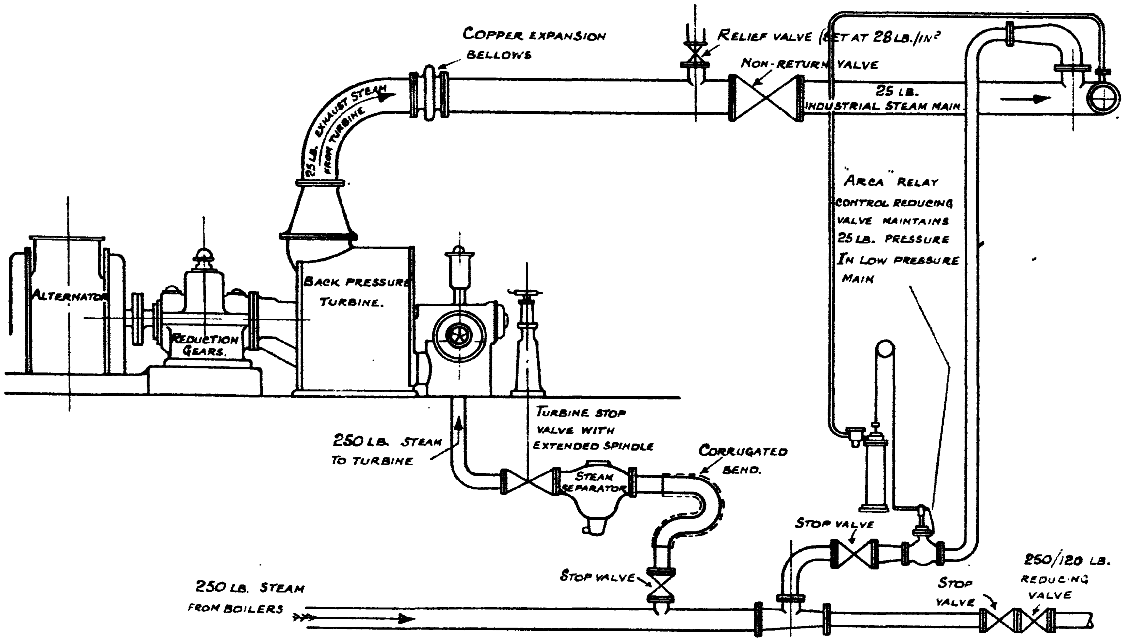


FIG. 40. DIAGRAM OF G.E.C.-FRASER & CHALMERS TURBO-ALTERNATOR SET

entirely free from oil or impurity, the turbine is more suitable, even with the high efficiency of modern oil separators, although Messrs. Belliss & Morcom do make engines specially designed for running without oil being admitted to the cylinders when using saturated steam.

Steam-extraction engines were developed as far back as 1887 by Messrs. Sulzer Bros.; in that year a type of cross-compound steam

FIG. 41. BACK-PRESSURE TURBINE
(*G.E.C.*)

engine was built with means for extracting the steam (for feed heating or process purposes) from the intermediate receiver. An automatic device controlled the pressure of the pass-out steam. Present-day steam-extraction engines are chiefly used for supplying steam either for low-pressure process work or for heating factory buildings, especially in cases where the steam needed for the production of power greatly exceeds the amount of process steam required. Steam-extraction engines are frequently arranged with high- and low-pressure cylinders in tandem; the compounding enables the final pressure to be lowered, with resulting economies. If there are considerable variations in the demand for process steam, it may be profitable to provide a steam accumulator (see pages 61, 63, 64). In any case, a heavy demand for process steam will justify passing a supplementary quantity of live steam through the engine

so as to prevent the output of power from falling below the normal figure. After being exhausted, the supplementary steam then passes on to the condenser. This arrangement can be made automatic in action, the make-up steam valve being actuated by a servo-motor. The general arrangement of the system is shown in Fig. 43.

Steam Accumulators. Where there are large fluctuations in the

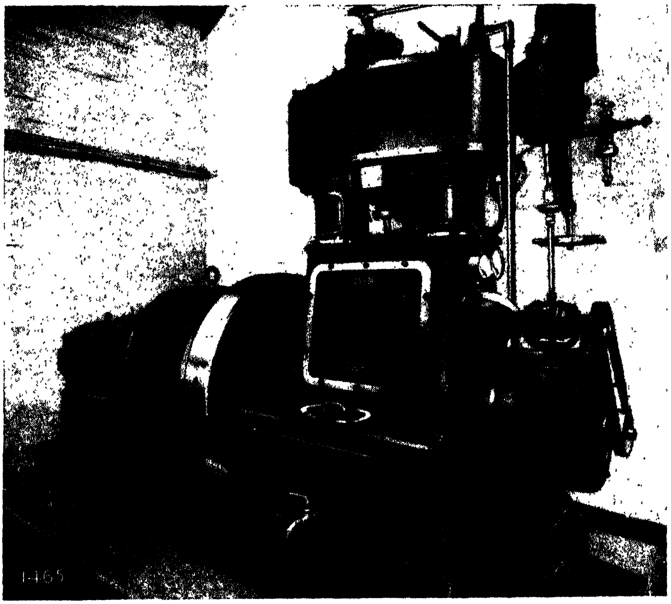
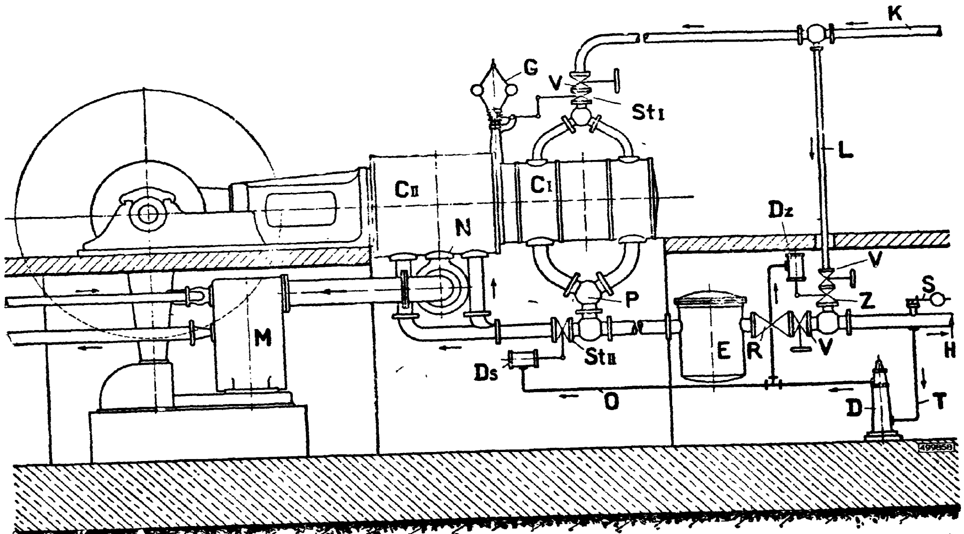


FIG. 42. BACK-PRESSURE RECIPROCATING ENGINE DRIVING DYNAMO
(*Belliss & Morcom*)

steam load or supply, or both, large economies can be effected by installing heat accumulators. A steam accumulator performs the same function in a steam generating plant as a flywheel does in a reciprocating engine, namely, as a device for storing energy which is used to meet the demands of a fluctuating load. There are two systems, the *pressure-drop* or Ruths system and the *constant-pressure* or Kiesselbach system, shown in Figs. 44 and 45 respectively.

PRESSURE-DROP SYSTEM. With this system the industrial or process steam pressure must be below the boiler pressure, fluctuations in the demand or in the boiler output being taken from the steam accumulator. The boilers can thus be fired at a constant rate and all steam not immediately required goes to the accumulator, which balances the varying demands for both high- and low-pressure



(Sulzer Bros. System)

FIG. 43. DIAGRAMMATIC ARRANGEMENT OF A COMPOUND ENGINE WORKING WITH STEAM EXTRACTION

C_I = High-pressure cylinder
C_{II} = Low-pressure cylinder
D = Oil-operated pressure-regulator
Ds = Servo-motor operating L.P. cylinder cut-off valve
Dz = Servo-motor operating live-steam make-up valve
E = Oil separator
G = Speed governor
H = Piping for heating steam
K = Piping from boiler
L = Live-steam make-up piping
M = Condenser
N = Exhaust ports to condenser
O = Pressure-oil piping
P = Receiver
R = Non-return valve
S = Safety valve
St_I = Cut-off valve to H.P. cylinder
St_{II} = Cut-off valve to L.P. cylinder
T = Steam pipe to pressure regulator
V = Stop valves
Z = Live-steam make-up valve

steam, and tends to keep the pressure steady in each range. The accumulator is connected through a control valve to the low-pressure or "industrial" mains carrying steam for process work. Briefly, the plant consists of a large cylindrical vessel suitably lagged, with non-return valves in the supply and delivery mains, allowing steam to enter from the supply and to pass out from the vessel to the industrial mains, the vessel being kept about three-quarters full of water.

The non-return valve in the lower pipe opens when the pressure in the main is higher than that in the accumulator. The valves in the upper pipe remain closed against the steam in the main, but they will open under pressure from the accumulator when the pressure therein exceeds that in the main. When the industrial load is light, steam passes from the boiler to the water in the accumulator and condenses, thus giving up its heat to the water. On the load increasing on the process steam side, the pressure drops slightly in the accumulator, so causing some of the water to evaporate, and thus reducing the load on the boilers.

Another advantage of superheated steam may be mentioned here, namely, that the steam remains dry throughout its expansion, provided that the superheat is sufficient, and in this way more heat is given up in useful work instead of being lost through condensation of the steam. This is particularly the case in reciprocating engine work where, due to the temperature range in the cylinders, the steam is inclined to condense at the lower end of the expansion stroke. It should also be mentioned that where steam is generated at high pressure it is sometimes an advantage to work engines at a lower pressure, first passing the steam through a reducing valve. This has the effect of superheating the steam, because, although the pressure drops, the energy content remains the same.

CONSTANT-PRESSURE SYSTEM. Where the load fluctuates and a constant pressure is necessary for industrial purposes, the constant-pressure type of accumulator is most suitable. The boiler drum is connected to the accumulator by an overflow pipe fixed at the water level so that water cannot rise above this height. Water is drawn from the bottom of the accumulator by a circulating pump which passes it through the boiler drum; the water then returns to the accumulator by way of the overflow pipe. By this continual circulation, water in the accumulator is kept at the same temperature as in the boiler. An equalizing pipe is also fitted, to connect the steam space in the boiler with that in the accumulator.

The boiler feed pump is controlled by a regulator operated by the boiler steam pressure, and can be slowed down or even stopped as the boiler pressure falls, whilst it accelerates when the pressure rises. An increased demand for steam, for instance, will thus reduce the supply of make-up feed water. Steam is then generated from the comparatively cool water entering the boiler from the circulating pump. Since latent heat *only* is needed to convert this water into

steam (as it is already at boiler temperature and pressure), an increase in evaporation will occur, provided that the furnace conditions remain constant. If the steam demand diminishes, the regulator causes the boiler feed pump to accelerate and deliver more cold water to the boiler. This water can absorb more sensible heat than that from the circulating pump, so that steam production is reduced and the extra water supplied is carried to the accumulator

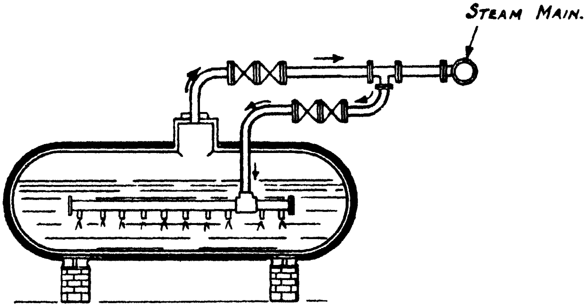


FIG. 44. RUTHS ACCUMULATOR: PRESSURE-DROP TYPE

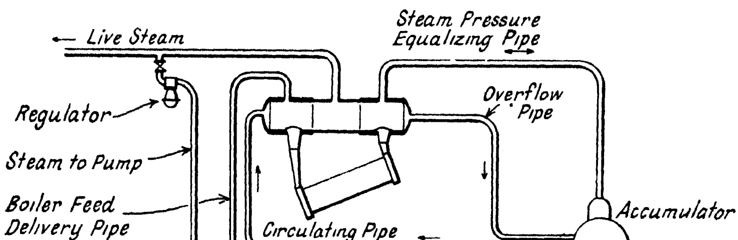


FIG. 45. DIAGRAM OF KIESSELBACH THERMAL STORAGE SYSTEM

through the overflow pipe. At peak loads, the accumulator supplies the entire boiler feed. Replenishment takes place at reduced loads. A pressure change of 2-3 lb. per in.^{2} is sufficient to operate the regulator, so that the boiler drum pressure is practically constant.

STEAM MAINS

All mains should be efficiently lagged and drained, and due care taken to see that allowance is made for expansion. Where there are steam mains of two or more pressures, each should be painted with

its own representative colour, as this ensures that serious mistakes are not made when connecting up low-pressure vessels. It also enables the fitter to see whether he requires high- or low-pressure fittings when working on alterations or additions. All modifications should be added (in their distinctive colour) to the steam mains layout drawing in the Plant Office.

Size of Mains. To arrive at the size of mains required for a given flow, the length of the main, number of bends, valves, permissible drop, etc., will have to be taken into account. Suitable flows for different sizes of main, with losses due to elbows, bends, valves, etc., are set out in Tables I and II.

Wherever possible, superheated steam should be used, especially if the mains are of considerable length, as the losses due to condensation are greatly reduced and velocities can be increased. Whereas the most efficient velocity recommended for saturated steam is 75 ft. per sec. for pipes up to and including 3 in. diameter, with superheated steam this can be increased to 100 ft. per sec. For pipes from $3\frac{1}{2}$ in. to 9 in. diameter, the figures are 90 ft. per sec. for saturated and 120 ft. per sec. for superheated steam. If these velocities are worked to, the drop in pressure will be negligible, providing there are no sharp bends or elbows. It must be remembered, of course, that the volume of 1 lb. of superheated steam is greater than 1 lb. of saturated steam, and the ratio is 1·15 : 1 for 100° F., 1·30 : 1 for 200° F., and 1·44 : 1 for 300° F.

General. All bends should be as gradual as possible. Valves of the full-way type should be used, thus keeping down the frictional losses. All mains should have a slight fall to the drain traps. Where rises in the main are necessary, a suitable trap must be installed at the bottom of the leg. Before laying out the main, the anchorage points should first be determined, and care exercised that the main is free to expand between these points. Wherever possible, an expansion bend should be fitted in preference to an expansion box, even if it is necessary to fit a corrugated bend, as the box would require attention from time to time, for the purpose of repacking and so on. Where flanges are screwed on, they should be suitably expanded. The main must be efficiently lagged. Tables III and IV give the sizes of British Standard Flanges, and Table V shows sizes of standard pipe fittings.

Pipe Hangers and Supports. It is always advisable to have standard types of pipe hangers and supports in a large works, for patterns can then be made and castings kept in stock, where necessary, so that a "rush" job can be done without waiting for the necessary fittings. Fig. 46 shows various types, any one of which can be adapted to suit individual requirements. It will be noted that side rollers for expansion bends are also shown. Care must be taken to see that pipework is free to move in a longitudinal direction.

TABLE I

Approximate Weight (lb.) of Saturated Steam per Min. Flowing Through 100 ft. Length of Pipe. Based on 1 lb. Pressure Drop per 100 ft. Run

INITIAL PRESS: BY GAUGE IN LB./IN.²	INSIDE DIAMETER OF PIPE (IN.)										WEIGHT OF 1FT.³ OF STEAM IN LB.	VOLUME OF 1LB. OF STEAM IN FT.³
	3/4	1	2	3	4	5	6	8	10	12		
1	0·353	0·815	5·91	18·35	40·6	74·4	121·8	263	474	765	0·0404	27·5
10	·436	1·005	7·29	22·6	50·0	91·9	150·7	324	585	944	·0614	16·30
20	·504	1·175	8·48	26·5	58·6	107·5	175·8	379	684	1093	·0841	11·89
30	·572	1·323	9·57	29·8	65·7	120·8	197·9	427	767	1240	·1065	9·39
40	·628	1·453	10·53	32·7	72·2	132·6	217	469	844	1360	·1285	7·78
50	·682	1·572	11·40	35·4	78·3	143·5	236	507	914	1475	·1503	6·65
60	·729	1·683	12·24	37·9	83·7	153·7	252	544	978	1579	·1721	5·81
70	·773	1·784	12·93	40·2	89·5	163·0	267	576	1037	1673	·1937	5·16
80	·815	1·880	13·62	42·4	93·5	171·9	282	607	1093	1763	·2151	4·65
90	·854	1·972	14·30	44·4	98·1	180·3	295	636	1146	1850	·2365	4·23
100	·892	2·062	14·91	46·3	102·8	188·2	308	665	1198	1932	·2577	3·88
120	·966	2·230	16·17	50·2	110·9	204	334	719	1293	2090	·3022	3·33
150	1·059	2·445	17·71	55·0	121·7	223	366	789	1420	2295	·3633	2·75

FORMULA for calculating the weight of steam flowing per min. through a pipe of given length and diameter.

$$W = 87\sqrt{\frac{PDd^5}{[1 + (3 \cdot 6/d)]L}}$$

where W = Weight of steam flowing in lb. per min.

P = Loss of pressure in lb. per in.^{2} over the length of pipe, and is given by $P = 0 \cdot 000132\left(1 + \frac{3 \cdot 6}{d}\right)\frac{W^2L}{Dd^5}$.

D = Weight of 1 ft.^{3} of steam.

d = Inside dia. of pipe in inches.

L = Length of pipe in feet.

V = Vol. in ft.^{3} of 1 lb. steam at initial pressure.

f = Friction constant $= 0 \cdot 0027[1 + (3 \cdot 6/d)]$.

The figures thus obtained will be reduced by the loss of head due to effect of accelerating to normal velocity, to the friction of the steam on entering the pipe, and to the passing of elbows and valves.

TABLE II

LENGTH OF PIPE (EXPRESSED AS MULTIPLES OF PIPE DIAMETER) EQUIVALENT TO THE RESISTANCE AT OPENINGS AND ELBOWS

Dia. in In. . . .	$\frac{3}{4}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	4	5	6	8	10
Openings and Globe Valves	20	25	34	41	47	52	60	66	71	79	84
Elbows . . .	14	16	22	28	32	35	40	44	47	53	56

TABLE III

British Standard Steam Flange Sizes

All dimensions in inches.

Nominal Pipe Size	Table D. For Steam Pressure up to 50 lb/in² — Dia: of Flange	Dia: of Bolt Circle	No & Size of Bolts	Thickness of Flange: Cast Iron	Cast Steel or Bronze	Iron or Steel Stamped or Forged	Table E. For Steam Pressures between 50 & 100 lb/in² — Dia: of Flange	Dia: of Bolt Circle	No & Size of Bolts	Thickness of Flange: Cast Iron	Cast Steel or Bronze	Iron or Steel Stamped or Forged
1/2	3 3/4	2 5/8	4. 1/2	1/2	3/8	3/16	3 3/4	2 5/8	4. 1/2	1/2	3/8	1/4
3/4	4	2 7/8	4. 1/2	1/2	3/8	3/16	4	2 7/8	4. 1/2	1/2	3/8	1/4
1	4 1/2	3 1/4	4. 1/2	1/2	3/8	3/16	4 1/2	3 1/4	4. 1/2	1/2	3/8	9/32
1 1/4	4 3/4	3 7/16	4. 1/2	5/8	1/2	1/4	4 3/4	3 7/16	4. 1/2	5/8	1/2	5/16
1 1/2	5 1/4	3 7/8	4. 1/2	5/8	1/2	1/4	5 1/4	3 7/8	4. 1/2	5/8	1/2	11/32
2	6	4 1/2	4. 5/8	3/4	9/16	5/16	6	4 1/2	4. 5/8	3/4	9/16	3/8
2 1/2	6 1/2	5	4. 5/8	3/4	9/16	5/16	6 1/2	5	4. 5/8	3/4	9/16	13/32
3	7 1/4	5 3/4	4. 5/8	3/4	9/16	3/8	7 1/4	5 3/4	4. 5/8	3/4	9/16	7/16
3 1/2	8	6 1/2	4. 5/8	3/4	9/16	3/8	8	6 1/2	8. 5/8	3/4	9/16	15/32
4	8 1/2	7	4. 5/8	7/8	11/16	3/8	8 1/2	7	8. 5/8	7/8	11/16	1/2
5	10	8 1/4	8. 5/8	7/8	11/16	1/2	10	8 1/4	8. 5/8	7/8	11/16	9/16
6	11	9 1/4	8. 5/8	7/8	11/16	1/2	11	9 1/4	8. 3/4	7/8	11/16	11/16
7	12	10 1/4	8. 5/8	1"	3/4	1/2	12	10 1/4	8. 3/4	1	3/4	3/4
8	13 1/4	11 1/2	8. 5/8	1	3/4	1/2	13 1/4	11 1/2	8. 3/4	1	3/4	3/4
9	14 1/2	12 3/4	8. 5/8	1	3/4	5/8	14 1/2	12 3/4	12. 3/4	1	13/16	13/16
10	16	14	8. 3/4	1	3/4	5/8	16	14	12. 3/4	1	7/8	7/8
12	18	16	12. 3/4	1 1/8	7/8	5/8	18	16	12. 7/8	1 1/8	1	1
14	20 3/4	18 1/2	12. 7/8	1 1/4	1	3/4	20 3/4	18 1/2	12. 7/8	1 1/4	1	1

Nominal Pipe Size	Table F. For Steam Pressures between 100 & 150 lb/in² — Dia of Flange	Dia: of Bolt Circle	No & Size of Bolts	Thickness of Flange: Cast Iron	Cast Steel or Bronze	Iron or Steel Stamped or Forged	Table H. For Steam Pressures between 150 & 250 lb/in² — Dia: of Flange	Dia: of Bolt Circle	No & Size of Bolts	Thickness of Flange Cast Steel & Bronze Stamped or Forged
1/2	3 3/4	2 5/8	4. 1/2	1/2	3/8	3/8	4 1/2	3 1/4	4. 5/8	1/2
3/4	4	2 7/8	4. 1/2	1/2	3/8	3/8	4 1/2	3 1/4	4. 5/8	1/2
1	4 3/4	3 7/16	4. 5/8	1/2	3/8	3/8	4 3/4	3 7/16	4. 5/8	9/16
1 1/4	5 1/4	3 7/8	4. 5/8	5/8	7/16	7/16	5 1/4	3 7/8	4. 5/8	11/16
1 1/2	5 1/2	4 1/8	4. 5/8	5/8	1/2	1/2	5 1/2	4 1/8	4. 5/8	11/16
2	6 1/2	5	4. 5/8	3/4	5/8	5/8	6 1/2	5	4. 5/8	3/4
2 1/2	7 1/4	5 3/4	8. 5/8	3/4	5/8	5/8	7 1/4	5 3/4	8. 5/8	3/4
3	8	6 1/2	8. 5/8	3/4	5/8	5/8	8	6 1/2	8. 5/8	7/8
3 1/2	8 1/2	7	8. 5/8	7/8	3/4	3/4	8 1/2	7	8. 5/8	7/8
4	9	7 1/2	8. 5/8	7/8	3/4	3/4	9	7 1/2	8. 5/8	1
5	11	9 1/4	8. 3/4	1	7/8	7/8	11	9 1/4	8. 3/4	1 1/8
6	12	10 1/4	12. 3/4	1	7/8	7/8	12	10 1/4	12. 3/4	1 1/8
7	13 1/4	11 1/2	12. 3/4	1	7/8	7/8	13 1/4	11 1/2	12. 3/4	1 1/4
8	14 1/2	12 3/4	12. 3/4	1 1/8	1	1	14 1/2	12 3/4	12. 3/4	1 1/4
9	16	14	12. 7/8	1 1/8	1	1	16	14	12. 7/8	1 3/8
10	17	15	12. 7/8	1 1/8	1	1	17	15	12. 7/8	1 3/8
12	19 1/4	17 1/4	16. 7/8	1 1/4	1 1/8	1 1/8	19 1/4	17 1/4	16. 7/8	1 1/2
14	21 3/4	19 1/2	16-1	1 3/8	1 1/4	1 1/4	21 3/4	19 1/2	16. 1	1 5/8

TABLE IV

BRITISH STANDARD STEAM FLANGE SIZES

The figures given in Tables L and M are for special welded-on flanges for use without valves or fittings.

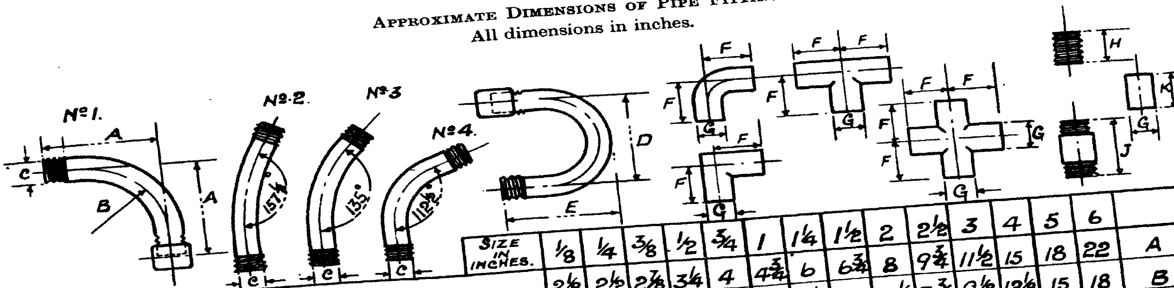
All dimensions in inches.

Nominal Pipe Size (in)	Table J — For Steam Pressures between 250 & 350 lb./in² — Dia. of Flange	Dia. of Bolt Circle	No. & Size of Bolts	Thickness of Flange Bronze or Stamped or Forged Steel	Table K — For Steam Pressures between 350 & 450 lb/in² — Dia. of Flange	Dia. of Bolt Circle	No. & Size of Bolts	Thickness of Flange Bronze or Stamped or Forged Steel	Table L — Special welded on flanges for Steam Press: up to 150 lb/in² — Dia. of Flange	Dia. of Bolt Circle	No. & Size of Bolts	Thickness of Flange Iron or Steel Stamped or Forged	Table M — Special welded on flanges for Steam Press: 150-250 lb/in² — Dia. of Flange	Dia. of Bolt Circle	No. & Size of Bolts	Thickness of Flange Steel. Stamped or Forged
1/2	4 1/2	3 1/4	4, 5/8	5/8	4 1/2	3 1/4	4, 5/8	3/4								
3/4	4 1/2	3 1/4	4, 5/8	5/8	4 1/2	3 1/4	4, 5/8	3/4								
1	4 3/4	3 7/16	4, 5/8	3/4	5	3 3/4	4, 5/8	7/8								
1 1/4	5 1/4	3 7/8	4, 5/8	3/4	5 1/4	3 7/8	4, 5/8	7/8								
1 1/2	5 1/2	4 1/8	4, 5/8	7/8	6	4 1/2	4, 3/4	1								
2	6 1/2	5	4, 3/4	1	6 1/2	5	8, 5/8	1	6	4 1/2	4, 5/8	1/2	6	4 1/2	4, 5/8	11/16
2 1/2	7 1/4	5 3/4	8, 3/4	1	7 1/4	5 3/4	8, 3/4	1 1/8	6 1/2	6	4, 5/8	5/8"	6 1/2	5	4, 5/8	3/4
3	8	6 1/2	8, 3/4	1 1/4	8	6 1/2	8, 3/4	1 1/4	7 1/4	5 3/4	8, 5/8	5/8	7 1/4	5 3/4	8, 5/8	3/4
3 1/2	8 1/2	7	8, 3/4	1 1/4	9	7 1/4	8, 7/8	1 1/4	8	6 1/2	8, 5/8	5/8	8	6 1/2	8, 5/8	7/8
4	9	7 1/2	8, 3/4	1 3/8	9 1/2	7 3/4	8, 7/8	1 3/8	8 1/2	7	8, 5/8	3/4	8 1/2	7	8, 5/8	7/8
5	11	9 1/4	8, 7/8	1 1/2	11	9 1/4	12, 7/8	1 5/8	10	8 1/4	8, 3/4	3/4	10	8 1/4	8, 3/4	1
6	12	10 1/4	12, 7/8	1 1/2	12	10 1/4	12, 7/8	1 5/8	11	9 1/4	8, 3/4	7/8	11	9 1/4	8, 3/4	1 1/8
7	13 1/4	11 1/2	12, 7/8	1 5/8	13 1/2	11 1/2	12, 1	1 3/4	12	10 1/4	12, 3/4	7/8	12	10 1/4	12, 3/4	1 1/8
8	14 1/2	12 3/4	12, 7/8	1 5/8	14 1/2	12 1/2	12, 1	1 7/8	13 1/4	11 1/2	12, 3/4	7/8	13 1/4	11 1/2	12, 3/4	1 1/4
9	16	14	12, 1	1 3/4	16	14	16, 1	2	14 1/2	12 3/4	12, 3/4	1	14 1/2	12 3/4	12, 3/4	1 1/4
10	17	15	12, 1	1 7/8	17	15	16, 1	2	16	14	12, 7/8	1	16	14	12, 7/8	1 3/8
12	19 1/4	17 1/4	16, 1	2	19 1/4	17	16, 1 1/8	2 1/4	18	16	16, 7/8	1 1/8	18	16	16, 7/8	1 1/2
14	21 3/4	19 1/2	16, 1 1/8	2 1/8	22 1/2	20	16, 1 1/4	2 3/8	20 3/4	18 1/2	16, 1	1 1/8	20 3/4	18 1/2	16, 1	1 5/8

TABLE V

APPROXIMATE DIMENSIONS OF PIPE FITTINGS

All dimensions in inches.



	Size in inches.	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4	5	6	
A	Centre to face of bends.	2 1/8	2 1/2	2 7/8	3 1/4	4	4 3/4	6	6 3/4	8	9 3/4	11 1/2	15	18	22	A
B	Radii of bends.	1 1/4	1 5/8	1 7/8	2 1/4	2 7/8	3 1/2	4 1/4	5	6 1/4	7 3/4	9 1/8	12 1/8	15	18	B
C	Outside dia: of bends & springs.	13/32	17/32	11/16	27/32	1 1/16	1 11/32	1 11/16	1 29/32	2 3/8	3	3 1/2	4 1/2	5 1/2	6 1/2	C
D	Centre to centre of W.I. double bends.	1 3/4	2	2 1/2	3 1/4	3 1/2	4 1/4	4 1/2	5 1/2	6	9 1/2	12	15	-	-	D
E	Back to face " " " "	2	2 1/2	2 3/4	3 1/2	4	4 3/4	5 1/8	6	7	9	11	13 1/4	-	-	E
F	Centre to face of elbows, tees & crosses	7/8	15/16	1	1 1/4	1 1/2	1 3/4	1 15/16	2 3/16	2 5/8	3 1/4	3 3/4	4 3/4	5 3/4	6 1/2	F
G	Outside dia: of elbows, tees, crosses & sockets	11/16	13/16	15/16	1 1/8	1 3/8	1 5/8	2 1/32	2 5/16	2 13/16	3 7/16	4	5 1/16	6 1/8	7 1/8	G
H	Length of nipples.	1/2	5/8	3/4	7/8	1	1 1/8	1 3/8	1 5/8	1 7/8	2 1/4	2 3/8	2 3/4	3	3 1/4	H
J	Length of barrel nipples.	1 3/8	1 1/2	1 5/8	2 1/8	2 1/4	2 1/2	2 3/4	3	3 1/2	3 1/2	3 1/2	4 1/4	4 1/2	5 1/2	J
K	Length of sockets.	3/4	1	1 1/8	1 1/2	1 5/8	1 7/8	2 1/8	2 3/8	2 5/8	2 7/8	3 1/4	3 1/2	4	4 1/2	K
Nos. 1,2,3 & 4	Length of tube in bends & springs.	3 5/8	4 1/4	4 3/4	5 3/8	6 1/2	7 3/4	9 7/8	11	13	15 3/4	18 3/8	24	30	36	Nos. 1,2,3 & 4
	When screwed on by hand the distance the tube screws into fitting =	5/32	3/16	1/4	1/4	3/8	3/8	1/2	1/2	5/8	11/16	13/16	1	1 1/8	1 3/8	

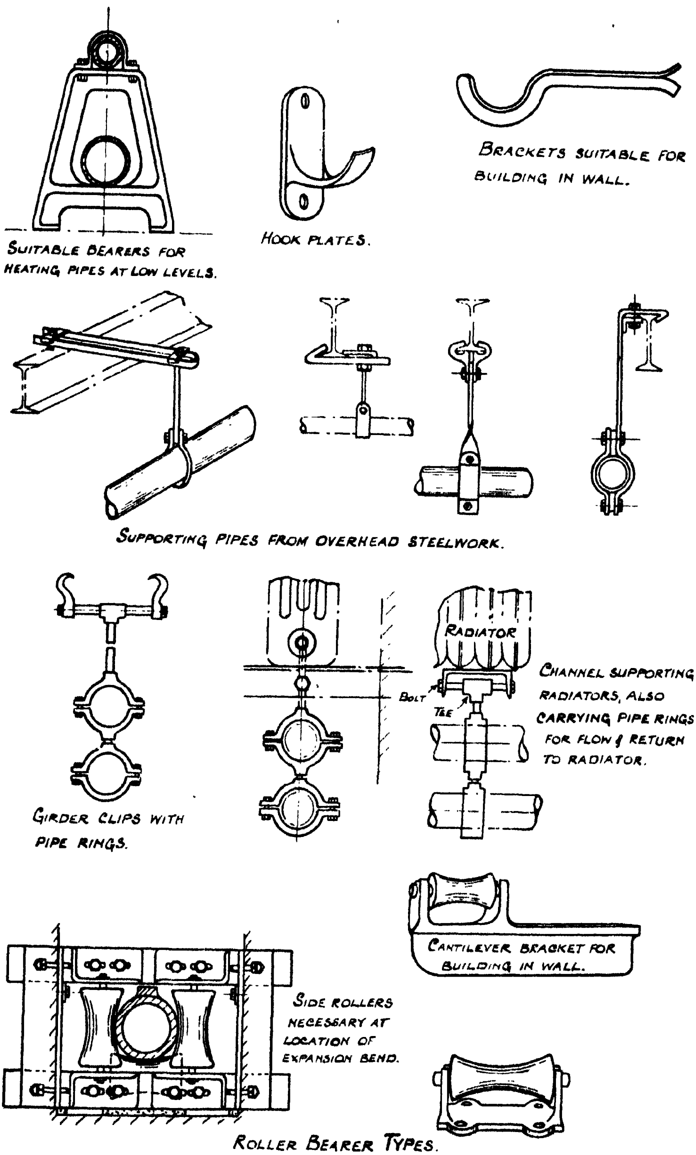


FIG. 46. TYPES OF PIPE HANGERS AND SUPPORTS

Lagging of Steam Mains. The radiation losses due to inefficient lagging are considerable. Not only should the pipes be lagged, but all flanges, tees, etc., will amply repay similar treatment. 1 ft.^{2} of uncovered pipe surface at 100 lb. per in.^{2} (gauge) will dissipate approximately 3 B.Th.U. per hour per degree of temperature difference between steam and atmospheric temperature, or 850 B.Th.U. per hour at normal temperatures. The percentage efficiency is based on the expression

$$\frac{\text{Heat loss from bare pipe---loss from covered pipe}}{\text{Heat loss bare pipe}}$$

TABLE VI

MATERIAL FOR LAGGING STEAM PIPES

Calculated on—

1 in. thickness of magnesia on all pipes under 5 in. diameter
1½ in. thickness of magnesia on all pipes over 5 in. diameter
1 in. thickness of hard-setting compound on all pipes

Nominal Size of Pipe	Magnesia, Volume per Foot Run (1 ft. = 8·4 lb. as Bought)	Hard-Setting Compound, Volume per Foot Run (1 ft. = 80 lb.)	Magnesia, Weight per 100 ft. Run in Pounds	Hard-Setting Compound, Weight per 100 ft. Run in Cwt.
1 in.	0·0518	0·0954	67·5	6·81
1¼ in.	·0627	·1070	81·75	7·7
2 in.	·0736	·1172	96	8·4
2½ in.	·0872	·1309	113·5	9·3
3 in.	·0981	·1418	128	10·13
4 in.	·1256	·1636	164	11·7
5 in.	·2290	·2142	299	15·29
6 in.	·2618	·2290	342	16·34
8 in.	·3280	·2727	482	19·47
10 in.	·3928	·3164	513	22·58

NOTE. Magnesia shrinks when wet. Thus 1 ft.^{3} when dry, weights 8·4 lb. ; when wet, 13·05 lb.

The best-known materials for lagging are magnesia, slag wool, and asbestos, although there is a number of good compositions under trade names. The materials adopted by the author for a number of years have been a coat of magnesia with a top covering of hard-setting compound. The thicknesses for different sizes of pipes are given in Table VI.

The main—under steam—should first be smeared with the hard-setting compound to give a "key" to help the magnesia to hold.

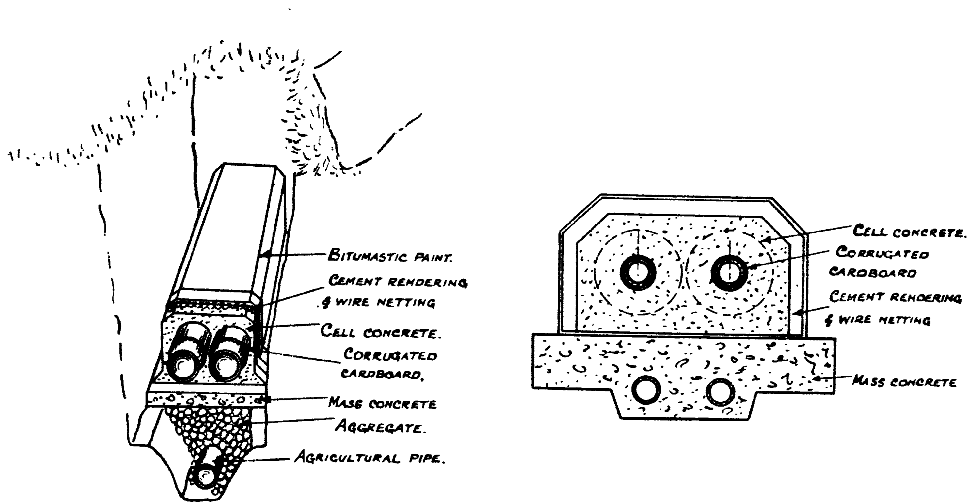
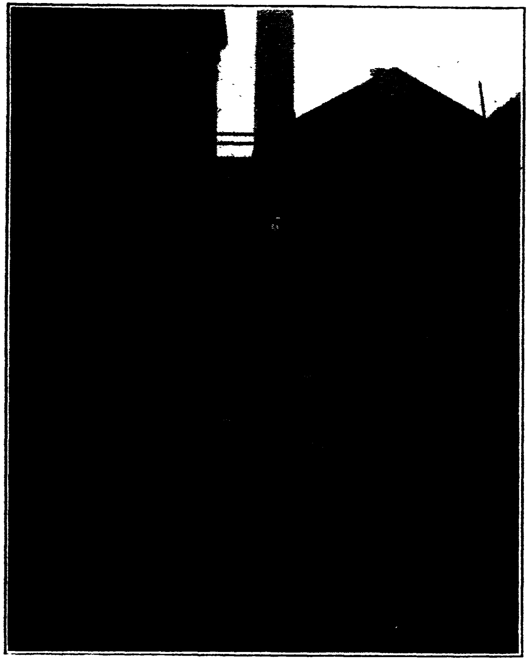
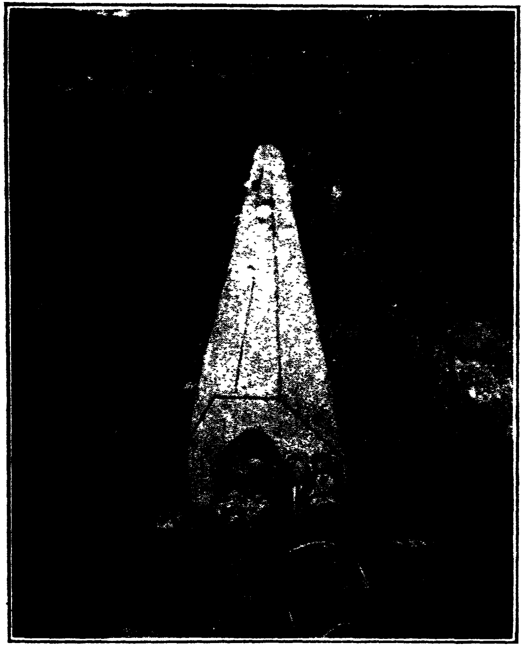


Fig. 47. Method of Covering Pipes with Cell Concrete

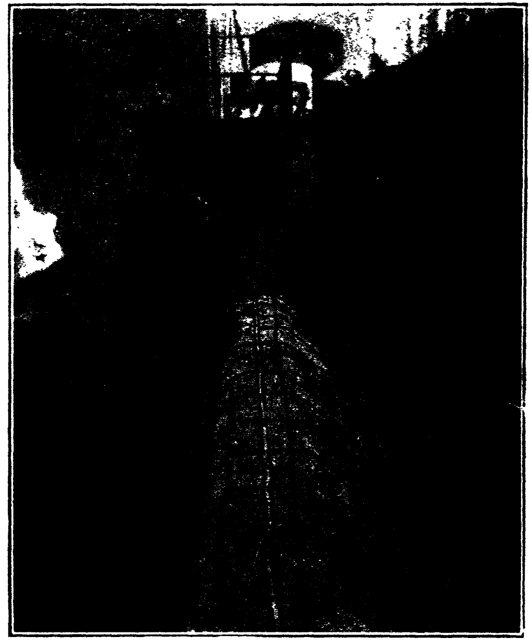


(a)

(b)



(c)



(d)

FIG. 48. CELL CONCRETE SHOWING INSULATION OF UNDERGROUND STEAM PIPES FOR LONG-DISTANCE HEATING

(a) The pipes covered with oiled paper
(b) Pouring the Cell Concrete
(c) The Cell Concrete after removal of the forms
(d) The Cell Concrete being covered with reinforced plaster

(*Christiani & Nielsen, Ltd.*)

Through subways, cellular sectional covering such as Bell's "Viceroy," is easily fixed and can be removed without damage for inspection or alteration to mains. The insulating efficiency of this covering is as high as 80 per cent, the thermal conductivity being 0·61 B.Th.U. per ft.^{2} per degree difference in temperature (National Physical Laboratory test). Whilst the first cost is higher, it is very adaptable in cramped positions. Suitable flange covers are also supplied.

Where a single or double pipe line is required under ground, and does not justify the building of a subway, the pipes can be buried, provided that they are set in Cell Concrete. Fig. 47 shows different methods of construction. It is advisable that all joints should be welded and tested before covering in. Cell Concrete insulation is a cellular cement product made from the same ingredients as ordinary cement mortar, with the addition of a foamy substance similar to soap-suds. Fig. 48 illustrates the method of covering with Cell Concrete, the photographs being taken on a contract for the Municipality of Copenhagen.

The mixing is done in specially built mixers, and every little foam bubble becomes covered with a film of cement mortar; thus, when set, the material is formed of numerous small air-filled cells. It is of very low specific gravity and is an exceptionally efficient insulalor against heat. It is also proof against vermin, is only slightly absorbent in water, and protects the pipes from corrosion. It is made in two grades, 18 lb. and 25 lb. per ft.^{3}, the latter being stronger but not quite such a good insulator. It has been used extensively on the Continent.

Slag wool gives the highest insulating efficiency, but due to the difficulty of attaching it, is very rarely used for steam mains. For ovens or steam-jacketed vessels where suitable containers can be fixed, slag wool should always be used.

Steam Traps. These can be divided under two headings: the *expansion* type which depends on the expansion of an element, in most cases a bellows or capsule; and the *float* type, which relies on the weight of water for its operation. In the former the operation depends on the expansion and contraction of the liquid which is sealed in the capsule or bellows. As steam passes around the capsule it causes the liquid inside to expand the capsule and shut the valve. Alternatively as water collects and cools the contents of the capsule, contraction takes place and the valve opens. In the float type, as the reservoir fills with water, a bell or float is lifted, thus opening the delivery valve to the condensate main. Whilst the former type can be very efficient, there is the possibility of the bellows becoming punctured, leaving the valve full open, whereas, in most of the float type steam traps, if the float becomes punctured the delivery valve closes. After trying numerous types of traps, the author's experience is that the float type gives better service, a breakdown being a very

rare occurrence providing the traps are overhauled once a year and the valves reground or replaced if necessary.

Condensate Mains. These may be either on the so-called *gravitation* system or the *vacuum* system. Where prime movers are used it is essential to have a vacuum system with vacuum pumps, etc., but where steam is used for low-pressure heating and industrial purposes requiring a pressure 25 lb. per in.^{2} and above, the gravitational system with lifting traps is perhaps the more economical. In

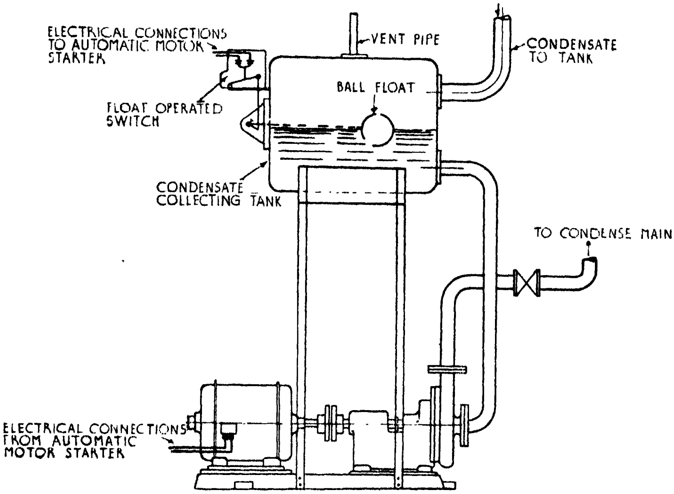


FIG. 49. DUNHAM CONDENSATION PUMP AND RECEIVER

a works covering 15 acres, the latter has operated successfully over a number of years. Where pressures have been below 25 lb., and in positions a long way from the boiler houses, automatic condensate pumps have been fitted, an example of which is shown in Fig. 49 These pumps work very successfully and give little trouble.

Condensate mains should be of ample size, all bends being of as large a radius as possible. Elbows should not be fitted, as frictional losses must be reduced to a minimum. All mains of 2 in. and over should be flanged, screwed, and expanded on, as the rush of water beating against the threads of pipe sockets will eventually wear them away. Fig. 50 shows fittings which were connected by screwed sockets instead of being flanged. Before leaving the subject of condensate mains, it might be stressed that when steam-heated hot plates, receivers, pans, etc., are installed, strict attention should be paid to the draining of the steam traps, so that water cannot accumulate, remembering that the risk of explosion in this type of plant is just as great as with a boiler.

Under the new Factories Act, which came into force on 1st July, 1938, all steam receivers and containers must be examined by a competent person, at least once in every 26 months, therefore it is advisable, especially where there is any possibility of corrosion or pitting due to process work, to have them insured, as they are then periodically inspected by a competent boiler inspector.

FIG. 50. EXAMPLES OF WEARING AWAY OF PIPES DUE TO THE USE OF SOCKETS INSTEAD OF EXPANDED-ON FLANGES

METERING

Water and Coal Measurements. The measurement of coal and water is, of course, the basis upon which boiler efficiency and costs are determined. Whilst care is usually taken of the water consumption, sometimes the measurement of the coal presents great difficulties and resort is therefore had to estimation.

COAL MEASUREMENT. The best method, of course, is to weigh the coal, and one of the best-known automatic coal weighers is the Avery. This machine is very accurate and robust. For the smaller plant, however, the first cost is perhaps rather high, and the requisite space is not always available.

Another type is the Bailey coal meter, consisting of a helical vane mounted on a vertical axis, in a vertical cylinder through which the coal falls. The falling of the coal causes the vane to rotate, the number of revolutions of the vane being a function of the volume of coal, passing by it. By connecting the vane to a counter, through flexible shafting, a record of fuel used is made.

The Lea Recorder Company have specialized in the manufacture of suitable meters for coal and feed water measurement, the Lea "Cubi-meter" being perhaps the best known of their products. As its name implies, it measures the number of cubic feet of coal, either passed over a belt conveyer to the furnace hopper or over a chain grate, and it is based on the following principle—

Ft^3. per hour = Width of conveyer $\times$ velocity of conveyer $\times$ thickness of coal stream.

The fundamental principle is that for a given depth of fire, the speed of the chain grate is a function of the volume of coal passing into the furnace. This will be readily understood by referring to Fig. 51. The meter is controlled by the position of the damper *D*

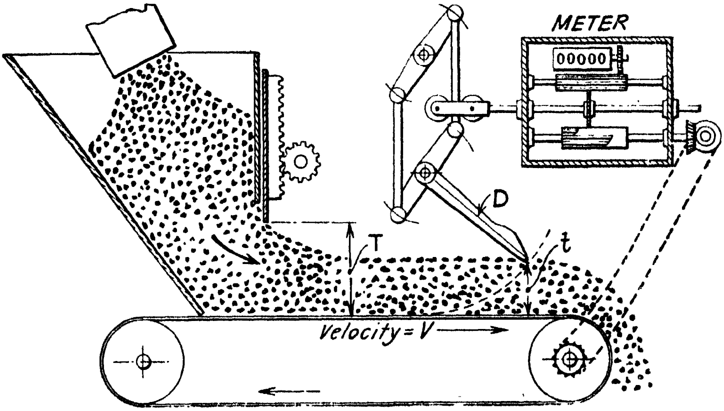


FIG. 51. DIAGRAMMATIC ARRANGEMENT OF "CUBI-METER"
(*Lea Recorder Co., Ltd.*)

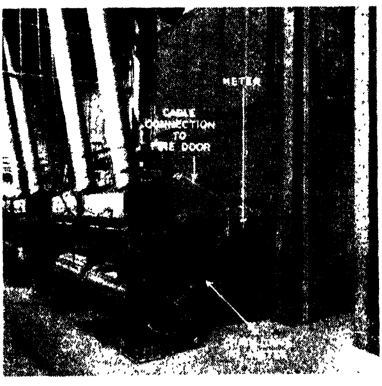


FIG. 52. LEA RECORDER ON CHAIN GRATE STOKER
(*Lea Recorder Co., Ltd.*)

which varies according to the thickness of the stream *t*. The manufacturers of the Lea meter guarantee an accuracy within $2\frac{1}{2}$ per cent for all grades of coal under average working conditions. Fig. 52 shows a chain grate installation which functions on the same principle as the cubi-meter.

Another device for the measurement of coal is the Romer-Lea

meter. This is shown in Fig. 53, which is self-explanatory. The chain is "immersed" in the coal, and travels with it, at the same speed, down the chute. The speed, which is proportional to the volume of coal passed, is recorded on the counter. Provided the chain "immersion" exceeds 6 ft., no slip takes place between the coal and the chain, and under normal conditions an accuracy to within 2 per cent is guaranteed.

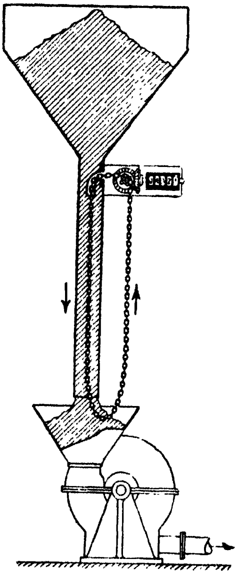


FIG. 53. "ROMER-LEA" METER (*Lea Recorder Co., Ltd.*)

Vertical chutes are, of course, ideal for this method of measurement, but the meter will work with the chutes slightly inclined.

The average weight of coal is about 48 lb. per ft.^{3}, but it is necessary when installing a meter to calibrate it to suit the class of coal in use. With fine slack the author has found, over a number of tests that the average weight is slightly more. Where it is not possible to install a measuring device, a good idea is to use a rail tipping tub for conveying the coal to the elevator hopper. The trimmer levels the top of the coal in the tub with his shovel, and if these tub loads are calibrated, fairly accurate measurements can be made. If pulverized fuel is used, the feed screw from the bin can be calibrated and a revolution counter fitted. Tests on pulverized coal (as fired) gave the average weight as 37·75 lb. per ft.^{3} Another method, where boilers are hand-fired, is to have a wooden or sheet metal gauge box, consisting of four sides without top or bottom, and of known cubic content, which is placed on the boiler house floor. This is filled level and then removed, leaving the coal which can then be shovelled on to the grate.

WATER MEASUREMENT. Where the flow is pulsating, i.e. as is the case with reciprocating pumps, the water should, if possible, be measured into a small suction feed tank. The Lea water recorder shown in Fig. 54 is one of the best-known types for this duty. This recorder works on the same principle as the coal cubi-meter, the height of the flow of water over a weir being measured.

In estimating water flow by measuring the discharge over a weir, the weir may be fitted either with a calibrated V-notch or a rectangular notch, the latter being reserved for large heads. If Q is the quantity flowing, in ft.^{3} per sec., and h the height (in feet) of the liquid passing over the weir, then for a 90° V-notch,

$$Q = 2{\cdot}54\, h^{5/2}$$

Such weirs may be used for metering feed condensate and blow-off discharge. Like the Lea boiler feed meter, they may be arranged to record the flow continuously by attaching to a float (arranged to one side of the path of flow) the usual spindle and recording pen. This pen indicates on a revolving drum the height of the water level, from which the flow over the weir can be read off.

When the flow is more or less steady, meters can be of the positive

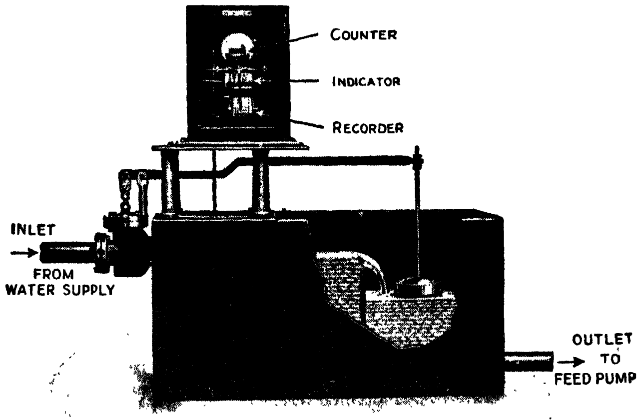


FIG. 54. LEA WATER RECORDER
(*Lea Recorder Co., Ltd.*)

type (such as the Kent uniform meter), or of the *Venturi* or *orifice plate* type; of the two latter meters the Venturi is the better, especially if the flow is not very steady.

All these meters depend on the relationship

$$V = C\sqrt{2gH}$$

where V is the velocity of the water in ft. per sec., H the head of water causing the flow, in ft., and C the experimental constant depending on the local factors. To be satisfactory in operation, such meters should be arranged to have a straight length of pipe ahead of them, the straight portion being at least twenty times the internal diameter of the pipe in length. Water should be clean, and free from scale, and care should be taken to prevent clogging or corrosion of the nozzles or orifices.

Where the make-up water is passed through a lime-soda softener, an approximate record of the quantity can be made by fixing an arm and counter on the tipping bucket, as shown in Fig. 55. If the bucket capacity is checked and the number of times it empties

recorded on the counter, fairly accurate measurements can then be obtained.

Steam Flow Measurements. The amount of steam used in any system can be measured by collecting and weighing the condensate, or by causing it to flow over a calibrated V-notch, or by metering the steam as it flows through the mains. The first two methods, being absolute measurements, are more likely to be accurate, but steam flow meters of good quality can give reliable

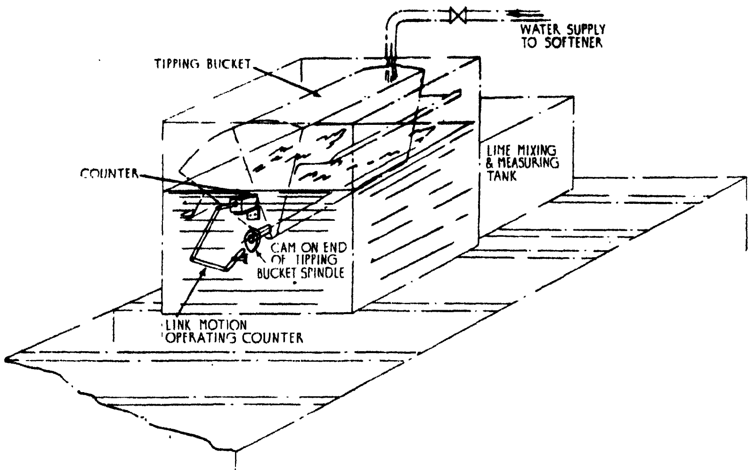


FIG. 55. METHOD OF CHECKING WATER PASSING THROUGH SOFTENER FOR BOILER FEED

readings. The chief points to be observed in using them are: (1) the steam main must be straight where the measurement is taken; (2) pressure and dryness fraction must be constant; (3) any changes in the flow rate must be gradual; and (4) the amount of steam passing through the main must be within the limits specified by the firm supplying the meter.

Steam Flow Meters. These meters are generally of the *orifice* and *Pitot tube* type, in which the basic operating power is the differential head created between the two pressure connections. This will be understood by referring to (*a*) in Fig. 56, which shows the flow through an orifice. The difference in head which results from the velocity of the steam flowing through a given size of orifice either operates on a mercury column or on a battery of spring-loaded metallic diaphragms, the latter arrangement being recommended where pressure compensation is required. An illustration of this type of meter is shown in Fig. 57.

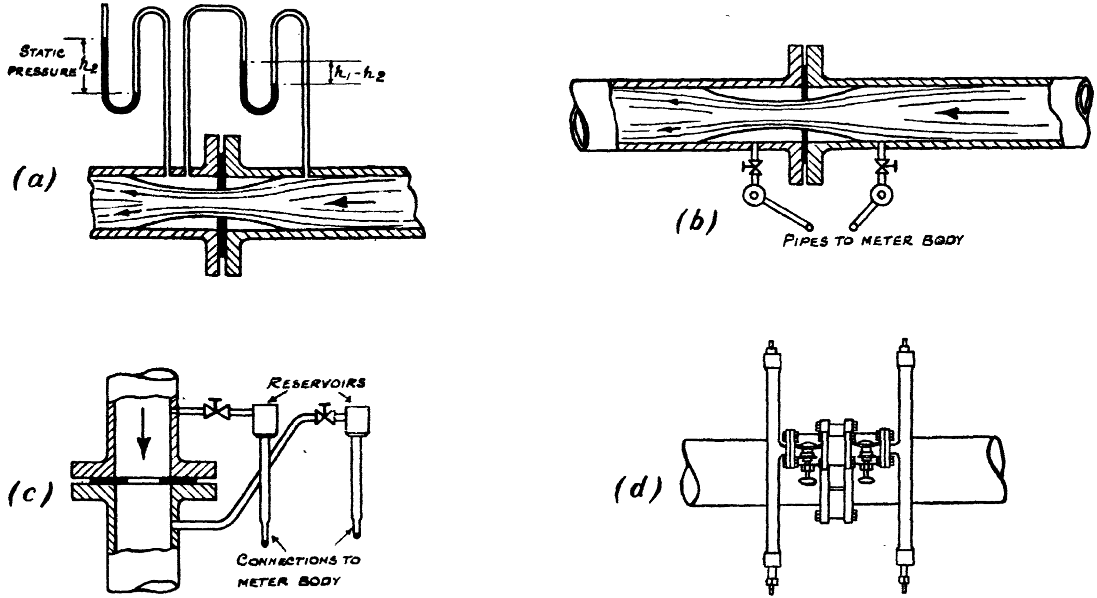


FIG. 56. MEASUREMENT OF FLUID FLOW THROUGH PIPES

(a) Diagram showing the principle of orifice measurement
(b) Plan of connections in horizontal main
(c) Method of fitting connections to vertical main
(d) Carrier Ring type orifice fitting

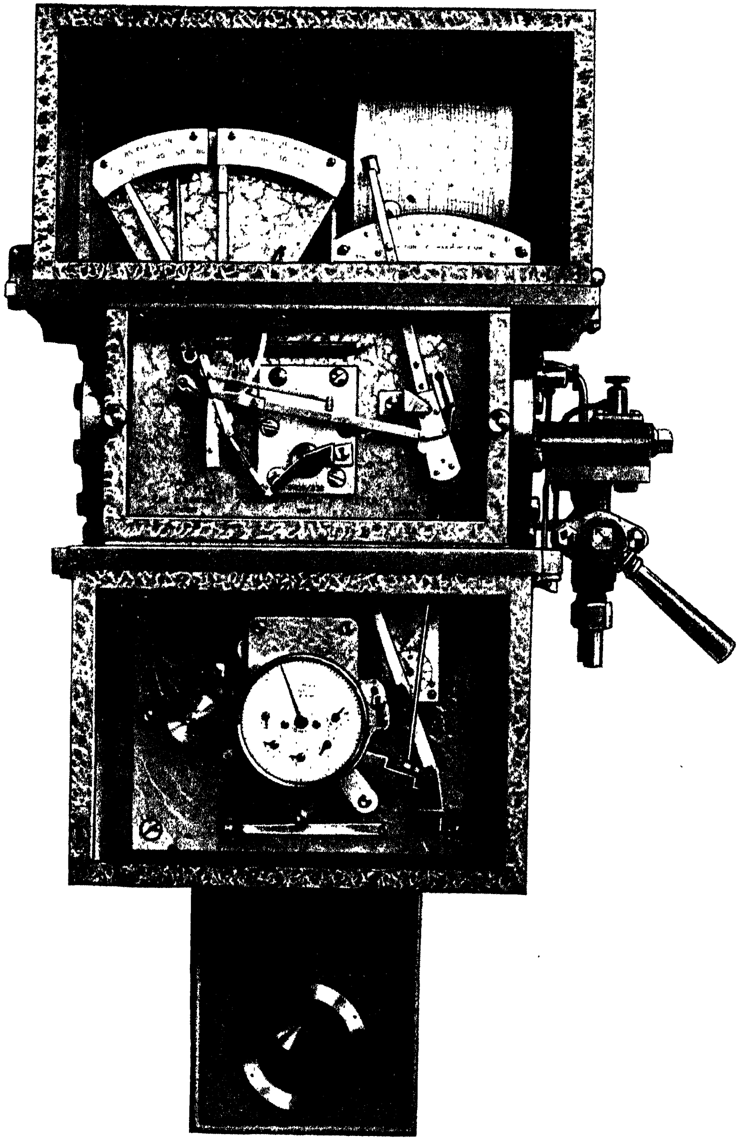


FIG. 57. PRESSURE-CORRECTED COMBINED DIAGRAM AND COUNTER STEAM METER
(*George Kent, Ltd.*)

Orifices may be of three types. The first, shown at (*b*), Fig. 56, consists of an *orifice plate* about $\frac{1}{8}$ in. thick which is fitted between convenient flanges on the steam main and held within the bolt circle. The pressure connections for the meter are taken by tapping the main on each side of the orifice plate. View (*c*) shows the method of connection for vertical mains.

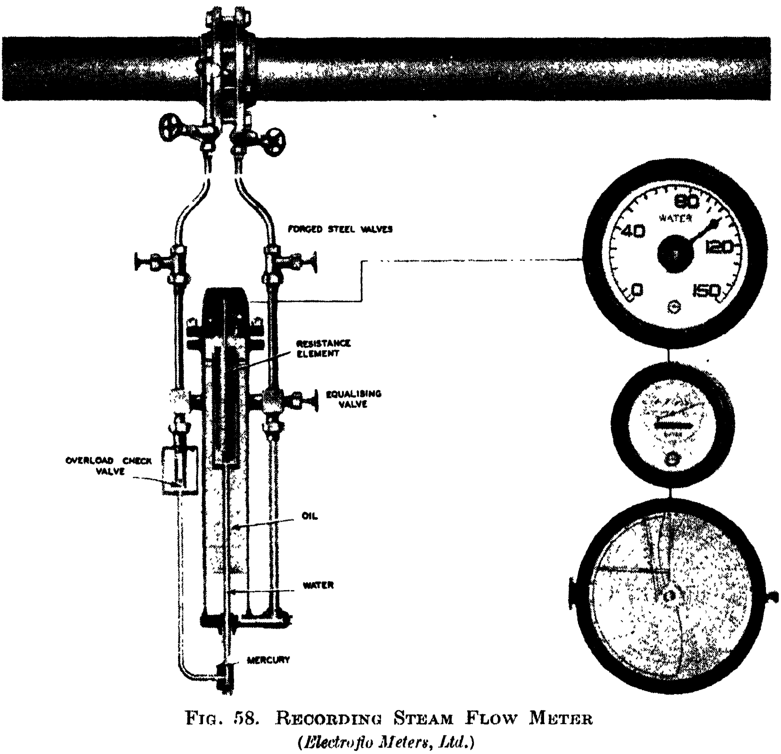


FIG. 58. RECORDING STEAM FLOW METER
(*Electroflo Meters, Ltd.*)

The assembly of the second type is shown at (*d*), Fig. 56, and consists of four parts, the *carrier*, the *orifice plate*, the *valves*, and the *cooling chambers*. This type should be used for steam measurement, for the reasons that (1) the construction of the carrier avoids errors due to pipe line construction, also the orifice plates can be easily changed; and (2) the fitting is self-contained, about $1\frac{3}{8}$ in. thick, and hence no drilling of the pipe line for pressure connection is necessary.

The third type consists of a short length of pipe with flanged ends containing a butterfly disc, which may be set in any of four fixed

positions. This gives a total flow range of eight times that of a single orifice. The orifice types should be installed with at least 10 diameters upstream and 5 diameters downstream of straight pipe, free from bends, tees, branch pipes, and control cocks. The possible combination of bends, valves, separators, and miscellaneous fittings is numerous.

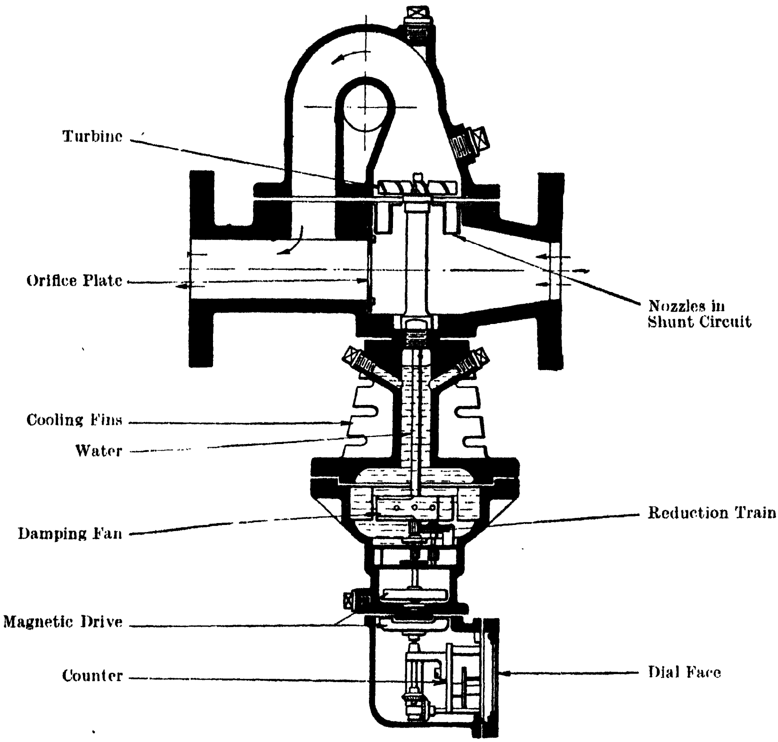


FIG. 59. TYPE "RS/C" SHUNT METER (LINE SECTION)
(George Kent, Ltd.)

There are several good combined indicating, integrating, and recording steam-flow meters on the market, such as the Kent "K.M.," the Bailey, and the Electroflo. The principle of the last is shown in Fig. 58. The meter body is a mercury manometer, subject to the differential pressure derived from the orifice plate (plain or carrier ring type) installed in the pipe line. The displacement of the mercury in the meter body brings it into contact with a continuous electrical resistance of special design, forming part of the electrical reading instrument circuit. As the mercury level varies with the

changes in differential pressure occasioned by alterations in the flow rate, the resistance of the reading instrument circuit is varied accordingly, the conductance being maintained exactly proportional to the rate of fluid flow.

The rate-of-flow indicator and the flow variation recorder are similar in construction to indicating and recording ammeters. The integrator is a totalizing conductance meter.

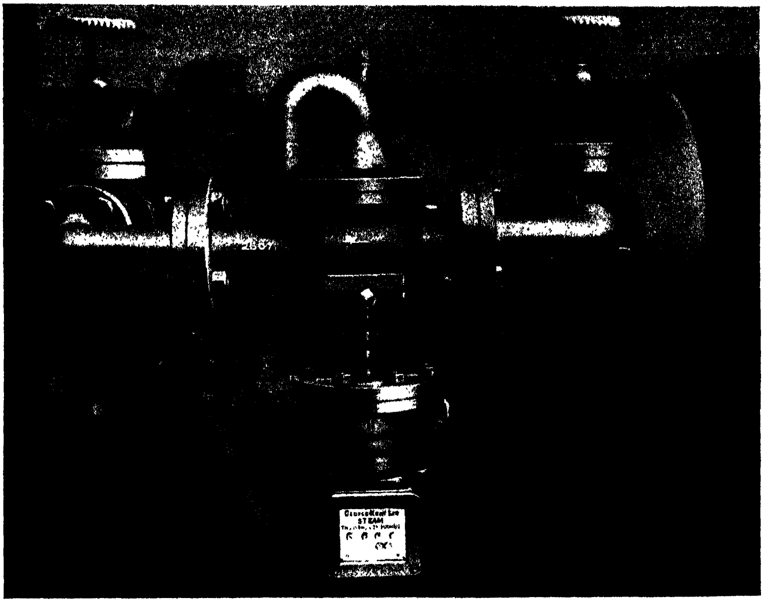


FIG. 60. SHUNT METER ON BYPASS FOR LARGE STEAM MAINS
(*George Kent, Ltd.*)

For branch mains up to 4 in. diameter the Kent shunt meter is perhaps the most economical form of meter, and a section of this instrument is shown in Fig. 59. When installing this meter, care must be taken to see that the specified length of straight pipe on each side of the meter is allowed for; this is usually 10 pipe diameters up stream and 5 pipe diameters down stream.

The shunt type of meter also affords an economical method of metering on larger mains, a small-size meter being installed as a shunt across an orifice plate inserted in the larger mains, as shown in Fig. 60. Such an arrangement proves very satisfactory, especially when the flow is a pulsating or intermittent one, as is the case in steam mains to colliery winding engines, etc.

A combined meter which may be regarded as a boiler efficiency

meter, made by Messrs. Bailey Meters and Controls Ltd., is shown in Fig. 61.

This meter, known as the Bailey boiler meter, records continuously the following quantities: the rate of steam output from the boiler; the rate of air flow through the furnace; and if desired, the average temperature of the flue gases. All these measurements are recorded on one chart. The recording pens are so arranged that if the air-flow

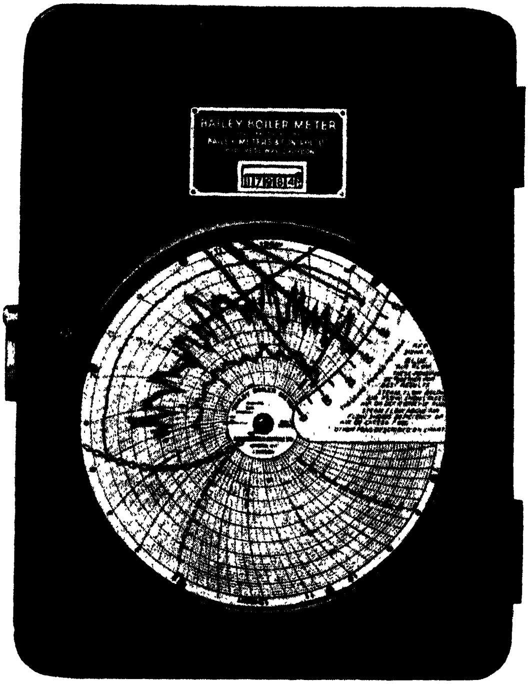


FIG. 61. BAILEY BOILER METER
(*Bailey Meters & Controls, Ltd.*)

line is above the steam-flow line, it indicates an excess of air with subsequent loss of heat in gases, due to that excess air; and when the air-flow line is below, it indicates deficiency of air, with resulting loss of heat due to unburned gases. The flue gas temperature record provides a check as to whether boiler baffles and flues are in proper order. The meter shown in the illustration is also fitted with steam-flow indicator.

Temperature Measurements.* For temperatures up to 400° F. the ordinary mercury thermometer can be used, while the high-quality

* Further particulars of thermometers and pyrometers are given on p. 335, Chap. XI.

nitrogen-filled type can be employed for temperatures up to 900° F. Above this figure a pyrometer is necessary. The pyrometer consists of three main portions: (1) the thermocouple of two different metals or alloys, fused together to form the "hot junction," the end which must be inserted in the thermocouple pocket placed at the point whose temperature is to be measured; (2) two leads connecting the hot junction to the indicating apparatus; and (3) the indicator proper, usually a millivoltmeter. The electromotive force set up in the hot junction when the latter is heated depends on the metals used, and varies between 70 mV. for base metal junctions to 16 mV. for rhodium-platinum junctions.

Another type of thermometer depends solely on the rise of pressure in a small bulb, containing liquid or gas, placed in the medium whose temperature is to be measured. A length of flexible capillary tubing connects the bulb to the recording mechanism, which is similar to a Bourdon pressure gauge, but with a recording pen and revolving dial. This apparatus is suitable for temperatures between − 60 and + 1 000° F. The capillary tubing should never be more than 100 to 120 ft. long, and therefore, in cases where the point whose temperature is to be measured is some distance from the indicator or recorder, a thermocouple is preferable.

Draught Gauges. The most sensitive gauge is the *air-bell* type, in which an air-bell is suspended in oil and is attached to the indicator operating gear by a quadrant and pinion, the connection from the flue being carried up into the bell without touching it. Proportionately to the suction, the bell becomes submerged or rises. Provided the oil level is maintained, there is nothing to go wrong with it. Electroflo Meters, Ltd., George Kent, Ltd, and Bailey Meters and Controls, Ltd. make gauges of this type. A multi-pointer draught gauge made by the last firm is shown in Fig. 62.

CO_2 Meters and Recorders. There are two principal types, exemplified in the Uehling Recorder and the Engelhard Gas Analyser. The former depends on the aspiration of flue gas by means of a steam jet. The flue gas is drawn through a filter, passing into an absorption chamber containing caustic potash solution, via an orifice. A second orifice is placed on the other side of the absorption chamber. The absorption of CO_2 by the caustic potash causes a drop in pressure between the two orifices, and this pressure drop varies with the percentage of CO_2 in the flue gases. Between the absorption chamber and the second orifice, two branch tubes are arranged, one leading to a

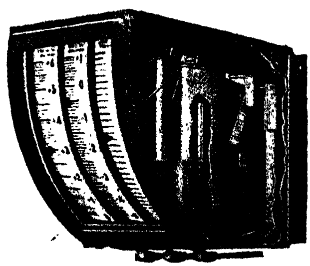


FIG. 62. MULTI-POINTER GAUGE
(*Bailey Meters & Controls, Ltd.*)

BOILERS UNDER STEAM 2 — Nº 1 BOILER

DAY	SHIFT	STEAM PRESSURE			STEAM FLOW																COAL FEED.											
					Nº 1 BOILER								Nº 2 BOILER																			
					METER READING				LB PER HOUR				METER READING				LB PER HOUR				Nº 1 SCREW				Nº 2				Nº 3			
		Highest	Lowest	Average	7	10	1	4	7	10	1	4	7	10	1	4	7	10	1	4	7	10	1	4	7	10	1	4	7	10	1	4
MON.	D																															
	N																															
TUE.	D																															
	N																															
ED	D																															
SA	N																															
SUN.	D																															
	N																															

WEEKS RUN		Nº 1 BOILER		Nº 2 BOILER		TOTAL
COAL CONSUMED	TONS					
	LB.					
STEAM GENERATED IN LB.						
FEED WATER IN LB.						
DRAUGHT AVERAGE.		1ST COUNT	2ND	1ST	2ND	

			ANALYSIS OF COAL.
CO_2	HIGHEST		
	LOWEST		
	AVERAGE		
FLUE TEMPERATURE	HIGHEST		
	LOWEST		
	AVERAGE		
STACK TEMPERATURE			
STACK DRAUGHT			
TEMPERATURE OF AIR AT PRIMARY FAN			WORKS ENGINEER'S OFFICE

EVAPORATION

Lb. per 1 lb. Coal
------as received

Lb. per 1 lb. Coal
------from & at 212° F

BOILER EFFICIENCY.

Nº 1. BOILER........%

Nº 2 BOILER........%

COMBINED EFFY......%

DRYER.

COAL CONSUMED BY FURNACE

------TONS D. S. NUTS

FIG. 63. BOILER

HOUSE WEEK ENDING FEB. 4 1934

				Superheat Total Temperature of Steam								Feed Water Consumption in Lb.								Feed Water Economiser Temperature												Feed Water	
No. 4				No. 1 Boiler				No. 2 Boiler				Meter Reading				Lb. per Hour				Inlet				Outlet				Difference				O	CC.
7	10	1	4	7	10	1	4	7	10	1	4	7	10	1	4	7	10	1	4	7	10	1	4	7	10	1	4	7	10	1	4	Hardness	Alkilinity

FINAL METER READINGS

Taken at 7am. ....

Steam Flow No. 1 Boiler. ....

No. 2 Boiler. ....

Kent Meter. ....

Feed Water. ....

Coal Feed No. 1 Screw. ....

No. 2 " ....

No. 3 " ....

No. 4 " ....

Elevator. ....

REMARKS. Cleaning, Inspecting, Repairs, etc.

Hours Steaming .... No. 1. No. 2.

No. 2 Boiler.

Engineer. .... BOILER HOUSE

Checked. .... WORKS ENGINEER

LOG SHEET

manometer or water column, whose height varies with the pressure between the orifices, and the other to the recording gauges.

The Engelhard system relies on the comparison of the resistance of two electrically heated wires, one passing through a "standard"

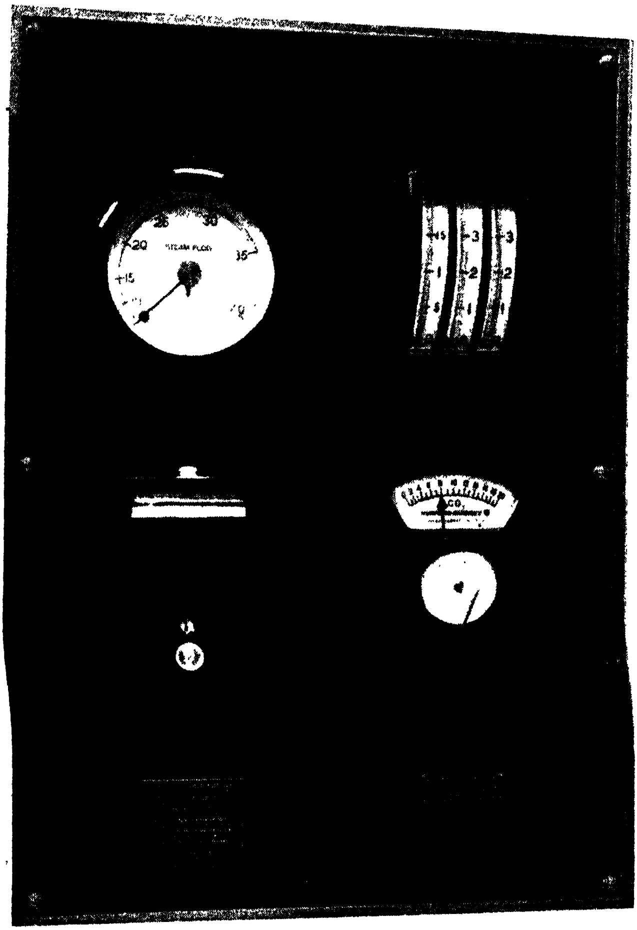


FIG. 64. INDICATING INSTRUMENT PANEL
(George Kent, Ltd.)

gas used as a reference, and the other through the gas to be analysed. The wires are of platinum, about 0·6 mm. diameter, and are coupled to a Wheatstone bridge system. When the two gases are of the same composition, the resistance of the electrically heated wire is equal, and the bridge will be balanced. Any difference in thermal

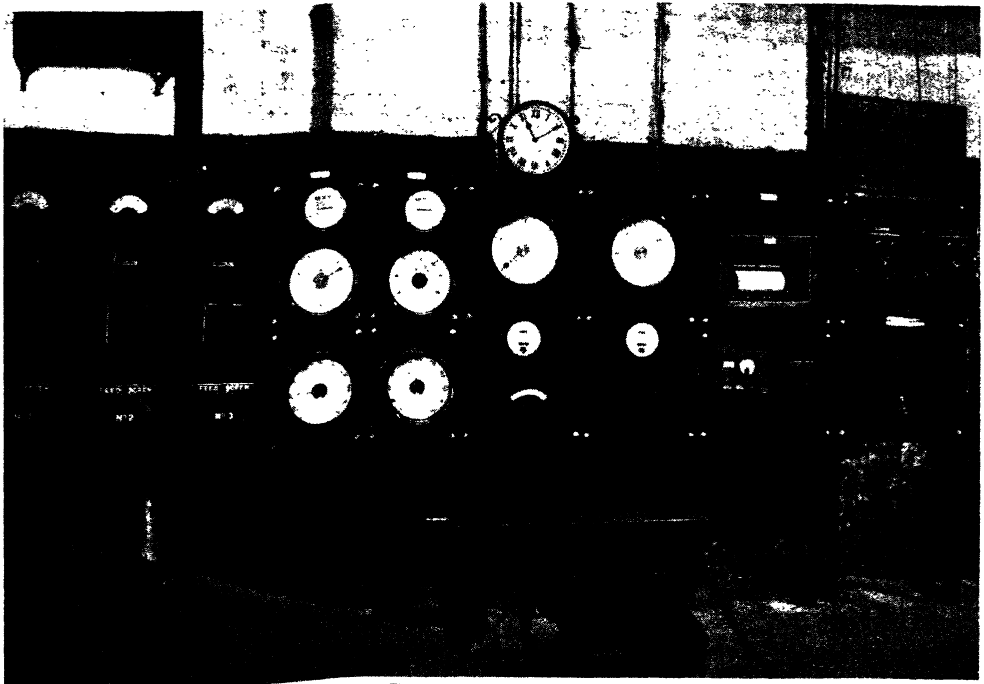


Fig. 65. Boiler House Recording Instrument Panel
(G.E.C.)

conductivity of the two gases will cause temperature differences in the wires, and will unbalance the bridge, which can be calibrated to indicate the CO_2 content of the gas being analysed. Recording instruments are fitted in addition.

CO_2 recorders are usually fitted with filters which become gradually clogged with impurities and dirt in the flue gases. To clean the filters, compressed air may be used; it should be passed through

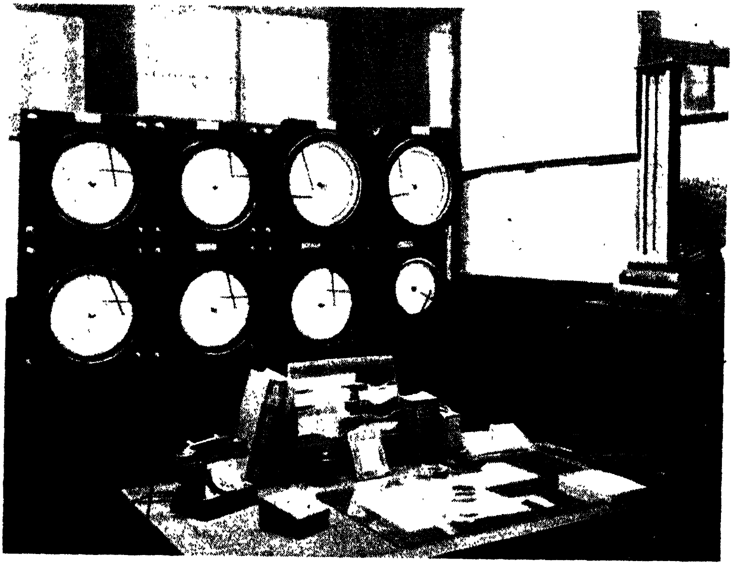


FIG. 66. RECORDING INSTRUMENT PANEL IN WORKS ENGINEER'S OFFICE
(G.E.C.)

in the reverse direction to the normal flow of gas. The pressure of the compressed air should be initially 10 lb. per in.^{2}, but may be increased to 15-20 lb. per in.^{2} as the operation proceeds. It is also most important to keep the pipe clean, between the filter and the flue gas intake. The author has used the Engelhard type for a number of years, with a minimum of trouble.

RECORDS

It is essential on all boiler plants, large or small, to have suitable instruments for the measurement of steam, feed water, fuel, superheat and feed water temperatures, and CO_2. Without these no proper check can be kept on steam-raising costs. It will be found, even on a small plant, that instruments soon pay for themselves.

An indicating instrument panel is shown in Fig. 64. A good form for a boiler log is shown in Fig. 63. The log book is of the loose-leaf type with two separate binders, one being kept in the boiler house and the other in the Works Engineer's office. The boiler house binder-leaves are in duplicate, the carbon copy being sent to the office each week for inspection and filing. On the plant where this system is used, the indicating and integrating meters for steam and

SLACK					
Date	Quantities Delivered			Used	Stock
	By Wilson	By Cory & Son.	By Cox.		
					Brot. Fwd. 919-1-1
5·2·34	3-1-0	12-1-2	27-10-0	30-6-0	
6·2·34	14-10-0	25-10-0	29-8-0	31-0-0	
7·2·34	18-7-0		34-12-0	30-10-0	
8·2·34	2-18-0			31-12-0	
9·2·34	12-8-0	11-3-0		32-0-0	
10·2·34				50-12-0	191-8-2
	51-4-0	48-14-2	91-10-0	+10% 206-0-0	883-17-3
12·2·34	18-6-0	19-4-0	11-3-0	32-0-0	
13·2·34		16-5-0	11-1-0	32-4-0	
14·2·34			10-18-0	32-6-0	
15·2·34	15-4-0		5-8-0	32-10-0	
16·2·34	9-4-0		15-4-0	31-10-0	
17·2·34	12-2-0			40-4-0	143-19-0
	54-16-0	35-9-0	53-14-0	+10% 200-14-0	807-16-3
19·2·34	18-6-0				
·2·34					

FIG. 67. COAL RECORD SHEET

feed water flow are installed in the boiler house and the recorders in the Works Engineer's office.

Fig. 65 illustrates the boiler house panel showing Electroflo and Kent steam and feed water flow meters, Bristol pressure indicator and transmitter, Cambridge CO_2 and flue temperature recorder, and Foster eight-point temperature indicator, together with Electroflo draught gauges, etc; whilst Fig. 66 illustrates the panel in the Works Engineer's office which includes recorders for steam and water flow, boiler pressure, and low-pressure steam, which are all that are necessary to portray the boiler house conditions.

The meter recorder charts are sent to the boiler house for their inspection each morning. At first, difficulty is experienced in getting the boiler attendants to fill in their records neatly on the log sheet, but with a little patience and help from their foreman, most men will soon learn to carry this out satisfactorily.

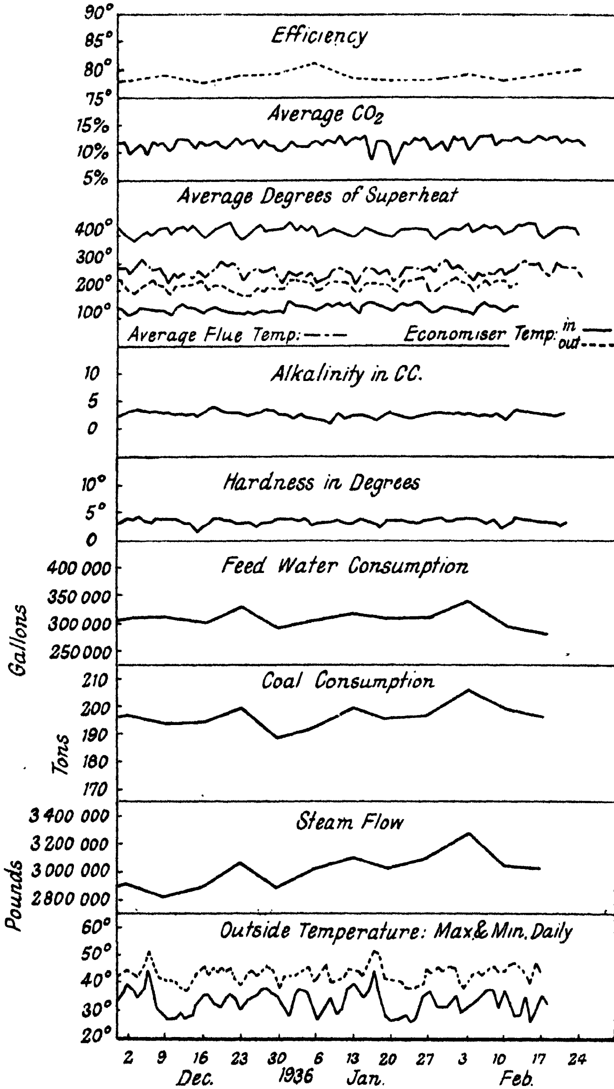


FIG. 68. GRAPHS SHOWING BOILER EFFICIENCY AND OTHER READINGS

ESTIMATED COST OF GENERATING STEAM.

Month. December/33 No. 1 BOILER HOUSE. No. of Boilers in use. 2.

Coal consumed Slack 1036 tons.

D.S. Nuts 12 " Feed water 1,667,468 gallons. Estimated Steam 15,880649 lb

Operating Expenses - Steam	Labour	Materials	Total	Remarks
Fuel used by boilers	£	£	£ 500.14.8 10.5.0	9/8 per Ton 17/1 " "
Water used by boilers		6.16.0	6.16.0	
Pay of Superintendence	47.10.0		47.10.0	
Miscellaneous Labour.	89.19.11		89.19.11	
Oil, Grease & Waste		8.4.1	8.4.1	
Electricity (Power) Electricity upkeep.		143.14.3 1.3.5.	144.17.8	
Light. Electricity upkeep.		1.6.2 11.4.	1 17.6	
Insurances		5.19.9	5.19.9	
RATES & TAXES.		7.2.6.	7.2.6	
TOTAL OPERATING EXPENSES £823.7.1.				
Maintenance Costs	54.6.6			
Depreciation & interest.	54.2.7			
Total Maintenance & Depreciation £	108 9.1			

Total Cost of generating steam £931.16.2

Pounds of steam generated 15,880,649.

Cost per 1000 lb of steam 1/2 $\frac{3}{4}$d

FIG. 69. STEAM GENERATION: MONTHLY COST SHEET

FROM May 31st 1936
To May 31st 1937

COST OF GENERATING STEAM.

	No. 1. BOILER HOUSE.		No. 2 BOILER HOUSE.
FUEL. SMUDGE.	6424 Tons	£3050.12.4	690 Tons £589.7.6
D.S. NUTS	312 "	266.10.0	
WATER.		79.9.10	36.8.1
SUPERINTENDENCE.		493.0.0	
OIL, GREASE, WASTE.		85.15.9	
POWER.		1126.7.10	12.18.0
LIGHT.		41.2.11	2.8.5
MAINTENANCE.		788.3.6	7.11.5
MISCELLANEOUS LABOUR.		793.13.10	199.4.3
DEPRECIATION & INTEREST.		671.5.0	84.2.0
INSURANCE, RATES & TAXES.		147.8.10	25.13.0
TOTAL COST OF GENERATING.		£7543.9.10	£957.12.8
LBS. STEAM GENERATED.		97,704,851.	13,137,600
COST PER 1000 LB.		s/1-6¾.	1s-5½d.

FIG. 70. STEAM GENERATION: ANNUAL COST SHEET

PULVERIZED COAL PLANT. BIN & FEED SYSTEM.
RUNNING COSTS & SAVING. YEAR 1935-1936.

WORKS ENGINEERS OFFICE.

MONTH	FUEL USED		FUEL COST		SUPERINTENDENCE & LABOUR	ELECTRICITY	WATER OIL, ETC.	MAINTENANCE	INSURANCE RATES & TAXES	STEAM GENERATED	TOTAL OPERATING EXPENSES	COST OF COAL IF ALL D.S. NUTS.	SAVING ON COAL.	FUEL PRICES.
193	NUTS	SLACK	NUTS	SLACK										
April														
May														
June														
July														
Aug.														
Sept.														
Oct.														
Nov.														
Dec.														
1937 Jan.														
Feb.														
Mar.														
TOTALS			£		£		£		£		£		£	
				£		£		£				£		

STEAM GENERATED AT No 1. BOILER HOUSE.		HEATED AREA.	GROSS SAVING ON COAL = £
1930-31	lb.	ft²	DEPRECIATION
1931-32	"	"	AS PER COST OFFICE = £
1932-33	"	"	5% INTEREST ON
1933-34	"	"	COST OF PLANT = £
1934-35	"	"	NET SAVING ON COAL = £
1935-36	"	"	COST PER 1000 lb STEAM, ALLOWING FOR DEPRECIATION = s. d.

FIG. 71. BALANCE SHEET FOR PULVERIZED COAL PLANT

DESCRIPTION LANCASHIRE BOILER (continuation) No 3 | INSURANCE Co REF: (3001 "A" Tested) | PLANT No 3/32 | PAGE No 3

MADE BY YATES & THOMPSON MAKERS No 3454 | WORKING PRESS. 120 lb/in² TEST PRESSURE 240 lb/in² | SUPPLIED BY MAKERS | PURCHASED 28/9/03. | LOCATION No 1 Boiler House

SUM INSURED £4000

REPAIRS, ETC.				INSURANCE EXAMINATIONS.			
NATURE OF REPAIRS	CARRIED OUT BY	DATE COMMENCED.	DATE COMPLETED	DATE OF EXAMINATION	CLASS OF EXAMINATION	REPORT	DATE OF REPORT.
				6-12-32	At work	In order where seen	24.12.32
				26-6-33	Entire (at rest)	" " " & but	
Note: Grates & Bridges to be removed for next Annual Examination						shell plates slightly	
						wasted.	9.8.33
				22.11.33	Ordinary (at rest)	In order where seen	8.12.33
				28.2.34	" (" ")	" " " "	7.3.34
				13.6.34	External & Internal	OK for 120 lb/in²	5.7.34
				17.8.34	Ordinary (at rest)	In order where seen	29.8.34
				27.9.34	Entire with lagging,		
					Grates, & Bridges	In order for	1.10.34
					removed.	120 lb/in² pressure	

FIG. 72. TYPICAL PAGE FROM RECORD OF BOILER INSPECTION AND REPAIRS BOOK

Feed water samples should be sent to the Works Laboratory daily; they will send a report direct to the boiler house, and a copy to the Plant Office.

Coal Records. A weight ticket is supplied with each load of coal and these tickets are sent to the office each morning, a record being kept as shown in Fig. 67.

Records and log sheets should be checked once a week by the costs clerk, who from graphs can work out the boiler efficiency, the whole being entered on a chart as shown in Fig. 68. It will be noted that outside minimum and maximum temperatures are recorded. Where a large heating load is necessary, this method gives a good indication as to variation in consumption. There are many charts from which it is easy for a costs clerk to work out the overall efficiency of a boiler plant. A very good one appeared in the *Power Engineer* for September, 1931, Vol. 26, page 351.

This method saves time and obviates the use of formulae, thereby making these calculations a routine job. It is quite good enough for commercial running, but should be checked periodically by the Works Engineer. (Formulae are given on page 33.)

It is a surprising fact that a number of fairly large firms are unable to tell what their boiler evaporation is, or the overall efficiency; they do not appear to realize that money can be saved by the efficient operation of their boilers.

A monthly sheet, as shown in Fig. 69, should be sent from the Costs Department, coal, water, and power being filled in in the Plant Office; thus the cost per 1 000 lb. of steam generated can be arrived at, and an annual sheet, Fig. 70, made out, giving the total annual cost. A more detailed balance sheet can be made out as shown in Fig. 71.

Records of boiler inspections and repairs are kept in a separate book, for ready reference; Fig. 72 shows a typical page from this book. From the details given it should be possible to make out a suitable set of records to suit large or small plants.

CHAPTER III

WATER, GAS, COMPRESSED AIR, AND VACUUM SYSTEMS

WATER

THE geographical position of a works has a large bearing on the cost of water used for industrial purposes. The three sources of water may be taken as: rain or surface water, rivers or springs, boreholes and wells. The cost of water obtained from town or corporation supplies is usually much higher than that of water supplied from other sources, due to the high maintenance and service charges in the case of the former. The average cost (1935) per 1 000 gal. to large consumers (using, say, 8 million gal. per annum), taken over fourteen cities and towns in Great Britain, is about 1s. 4½d., and great savings can be made in water costs if works are furnished with their own equipment for an alternative supply. Water containing iron is highly undesirable in certain industries such as dyeing and paper-making and care must be taken in tapping a new supply. It is advisable, however, to use town's water for drinking and canteen cooking, since a careful check as to purity is always kept by municipal bodies.

If a works is adjacent to a river or canal, the water—depending on the type of manufacture—can usually be made suitable for use by filtration, and by softening if necessary.

Sedimentation, i.e. allowing the suspended impurities to settle, is the simplest method of purification, and may be used in conjunction with the slow type of filtration to be described. The degree of purification which is possible through sedimentation varies with the time allowed for settling, but external considerations such as the economic size of the storage reservoir, have a bearing on this question. At least twenty-four hours' sedimentation should be allowed for general purposes. Allowance must be made, in estimating the reservoir capacity, for avoiding influx of storm water, which holds a large amount of matter in suspension, but at the same time there should be sufficient storage to provide against drought.

Filtration. There are two methods of filtration, *slow* and *rapid*. In the slow method the filter beds, of sand, are open at the top and the rate of percolation is about 4 vertical inches per hour. This type of filter lends itself to the use of a coagulant (see p. 38) and sedimentation. It is worked from a natural head and is therefore not affected by fluctuations in the pressure. Larger tanks are necessary than with the rapid or pressure type; also two sets of pumps may be required, one to pump from the source of supply, and one for

pumping from a clean water tank to an elevated tank for works supply.

The true effectiveness of the sand filter lies in the formation of an organic deposit on the surface. This deposit prevents bacteria from passing through the filter and assists in nitrifying organic impurities, but its disadvantage is that it tends to clog the sand. It is therefore necessary to remove this deposit periodically, although this operation can be somewhat delayed by adding minute amounts of copper sulphate. The duplication of filter beds is therefore

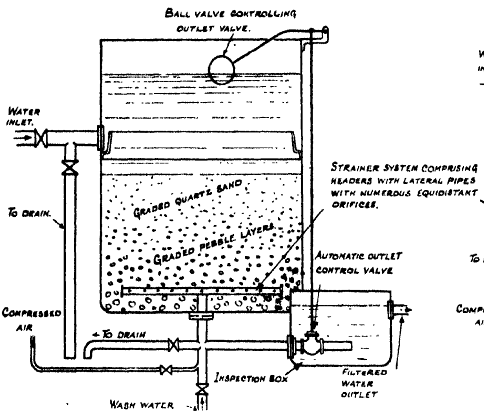


FIG. 73. GRAVITY TYPE FILTER
(Cleansed by compressed air)

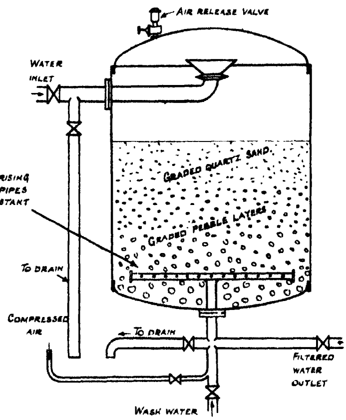


FIG. 74. PRESSURE TYPE FILTER
(Cleansed by compressed air)

necessary to ensure that filtered water shall always be available when either of the beds is being cleaned; in addition to this heavy capital outlay, the running costs of this type of filter are high.

The rapid or pressure type takes up less space and can be installed in the supply main with very little reduction in head, the one set of pumps passing the water through the filters to the elevated storage tank. The rapid process is roughly fifty times faster than the gravity type. Two well-known filters are the Paterson and the Heenan & Froude. The arrangements of the two main classes of filters—gravity and pressure—are shown diagrammatically in Figs. 73 and 74. Cleaning is effected by blowing compressed air upwards through the sand, to loosen it and to remove foreign matter; this reverses the direction of the flow, and the water is carried by the overflow pipe to the drain. About 12–15 min. flow in the reverse direction should be allowed every two to three days, according to the nature of the water supply.

Boreholes and Artesian Wells. Boreholes are perhaps the best-known source of industrial water supply. They may be Artesian,

in which the water rises to the surface under natural hydraulic pressure, or the water may have to be pumped. The *true* Artesian well, from which water rises right up to the surface of the ground, is rather rare. It is very common, however, to find this type sending water to within, say, 20 ft. of the surface, after which mechanical means can be used for raising the water.

Any of the well-known well sinkers, such as Islers, will give free advice as to whether the strata in a given locality are water-bearing, and the probable necessary depth of the borehole. The number of wells in the vicinity can be checked from the Geological Survey Sheets which can be bought from H.M. Stationery Office for 1s. 6d. each. The cost of boring depends on the diameter and depth of the borehole, and the following example gives the cost (1934) for a 12 in. to 10 in. borehole in the Midlands, having a depth of 400 ft., with steel casing throughout, 271 ft. being 12 in. diameter with one length of 40 ft. perforated, and the remainder 10 in. diameter perforated throughout. The cost, including the casing, was £895, or £2 4s. 9d. per ft. depth. The pumping water level is 43 ft. from the surface. This well yields 10 000 gal. per hour and augments a 10 in. borehole sunk nine years previously, which pumped an average of 47 million gal. per annum, the cost per 1 000 gal. pumped being 0·9d.

Where the borehole passes through marl and similar beds it is always advisable to line it with steel casing which should be perforated at the water-bearing beds; very often the shutting out of the water from water-bearing beds at shallow depths will reduce the hardness and increase the organic purity.

Pumps. Although the maximum theoretical suction lift, under normal barometric pressure, should be about 33¾ ft., such a perfect exhaustion of air in the suction pipe is unattainable in practice. Owing to the various losses, the limiting height above water level at which a pump can work satisfactorily is thus about 25 ft. Where the water level is more than this distance below the ground surface, it is necessary to sink the pumps to a suitable depth down the borehole. Such pumps are known as *borehole pumps* and can be classified under three main categories: *airlift*, *reciprocating*, and *centrifugal*.

Airlift Pump. This is perhaps lowest in capital cost. Its chief advantages are: (1) absence of moving parts and valves, so that even with the presence of much sand or mud, the pump will not become clogged; and (2), only a small space is required. The pressure of the compressed air will vary according to the lift required, but will have to be about 70 lb. per in.^{2} for a lift of 100 ft. This type of pump is not suitable if the total lift exceeds 250 ft. Although it is perhaps the lowest in capital cost, the efficiency is not great; also, due to the amount of rising main to be "sunk" below the water level, the borehole may have to be carried deeper. A 200-ft. lift would require a 100 ft. submergence. The great drawback to the airlift

pump is the contamination which is caused by oil carried over with the air from the compressor.

RECIPROCATING PUMPS. The chief characteristics are simplicity and massiveness of construction. This type of pump requires very little attention and is easily dismantled. Whilst the running costs are very low, the capital cost is much higher than for other types, more excavations, foundations, larger pump houses, etc., being required.

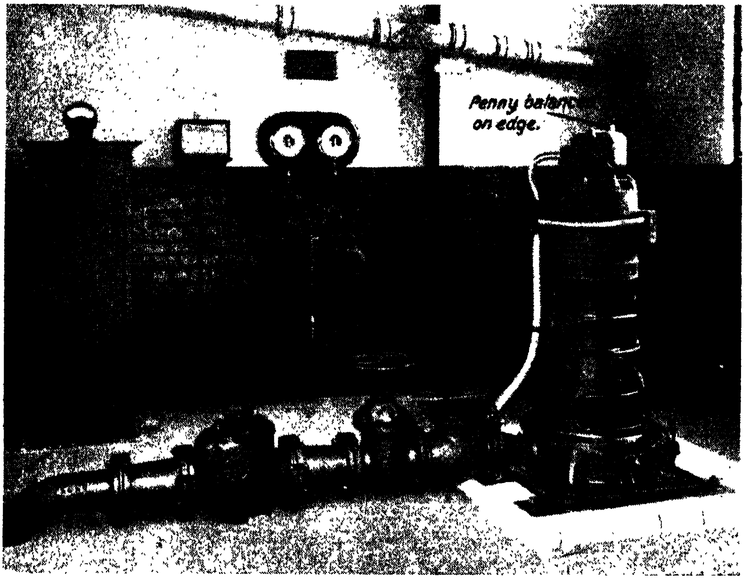


FIG. 75. SULZER CENTRIFUGAL PUMP DRIVEN BY G.E.C. VERTICAL MOTOR

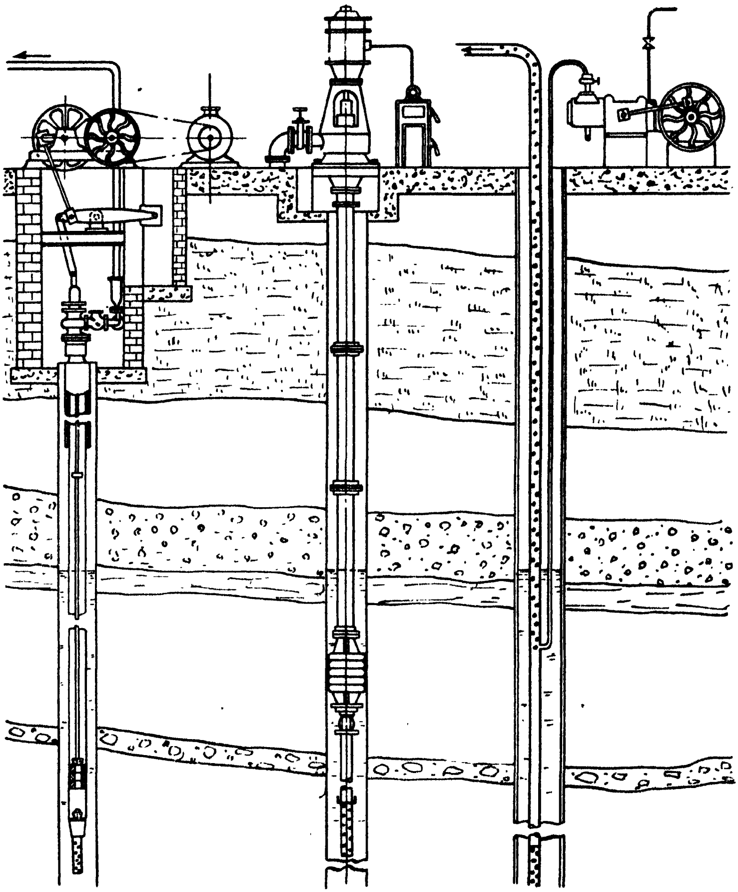
1 450 r.p.m. Delivery: 10 000 gal. per hr.

(*G.E.C.*)

Also, it may be necessary to have an increased size of bore for a given quantity of water. The top gear consists of the connections to the driving shaft, the gear wheels, the counterweight to balance the weight of plunger and rod, and the air vessel, which assists in making the discharge even and in absorbing shocks. In order to ensure a nearly vertical pull on the rod on the working stroke (the upstroke), the pump is often set out of centre with the crankshaft of the top gear. When the drive is by an electric motor, a flywheel should be provided to ensure constant current consumption and to prevent overloading, by making the torque more even.

CENTRIFUGAL PUMPS. The main points in favour of the centrifugal pump are: (1) minimum of floor space required; (2) low capital

outlay; (3) minimum diameter and depth of borehole; (4) absence of valves. The additional advantage is that these pumps can be operated automatically by a ball float in a tower some distance away.



(a) (b) (c)

FIG. 76. TYPES OF BOREHOLE PUMPS

(a) Reciprocating (b) Centrifugal (c) Airlift

The maintenance costs are very low; in one case this amount, over a period of nine years, was only a little over £5 per annum; and the overall efficiency is as high as 70 per cent. For low lifts (below 150 ft.) it is sufficient to employ a single-stage pump with one

impeller. Above 150 ft. lift, multi-stage pumps are required. For boreholes of very small diameter, an axial flow impeller is an advantage, as it requires less space. Special bearings are provided to take the thrust along the shaft. It is most important that the borehole should be absolutely vertical. Centrifugal pumps only show their greatest efficiency at one particular speed, and this should be borne in mind when arranging the driving mechanism. Fig. 75 shows a

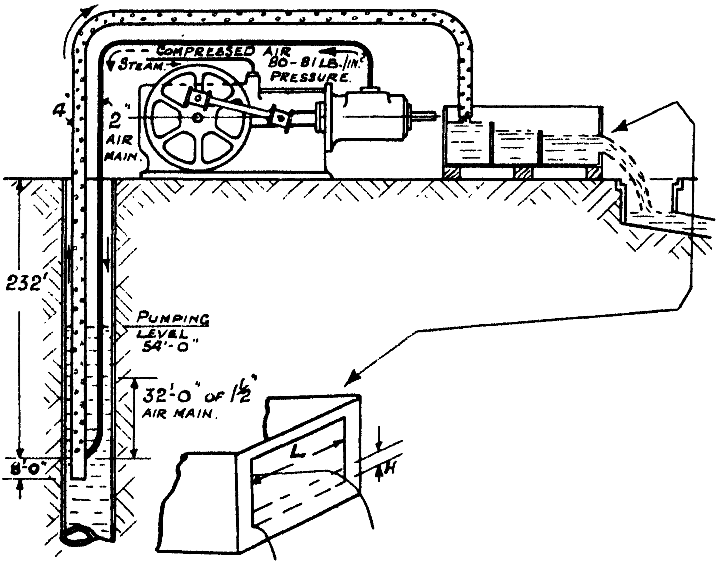


FIG. 77. PUMPING TEST BY AIR LIFT AND WEIR BOX

Sulzer centrifugal pump driven by a G.E.C. vertical motor at 1 450 r.p.m. and dealing with 10 000 g.p.h. The absence of vibration is illustrated by the penny balanced on the top of the slipring casing. The coin stood up for fourteen days with the motor automatically stopping and starting.

Fig. 76 shows the three types of pumps.

Tests. When a borehole is completed, it is usual to make running tests over three or four days, an airlift pump being generally utilized for this purpose. The discharge from the pump is measured by causing it to run along an improvised open channel, known as the *weir box;* or, as is usual for deliveries up to 15 000 to 20 000 gal. per hr. a wooden box, as shown in Fig. 77, is employed, a rectangular weir being arranged at the downstream end. Since the weir is rectangular, its width is a constant quantity, and therefore any variation in the flow only affects the height of the water over the weir. Fig. 78 shows a test plant in operation.

Fig. 78. Pumping Test in Operation
(G.E.C.)

An empirical formula for the calculation of the quantity flowing is—

$$\text{Gallons per hour} = 74\,700\,[L - (H/5)]H\sqrt{H}$$

where L = length of weir in *feet*
and H = height of flow in *feet.*

EXAMPLE. Calculate the flow over a weir 18 in. long when the average height of flow is 2·8 in.

$$\text{Flow} = 74\,700\left(\frac{18}{12} - \frac{2{\cdot}8}{5 \times 12}\right) \times \frac{2{\cdot}8}{12}\sqrt{\frac{2{\cdot}8}{12}}$$
$$= 74\,700\,(1{\cdot}5 - 0{\cdot}046) \times 0{\cdot}233\,\sqrt{0{\cdot}233}$$
$$= \underline{12\,176}\ \text{gal. per hr.}$$

Obviously, the accuracy of the measurement of H is very important. If a recorder is not obtainable, H must not be measured on the

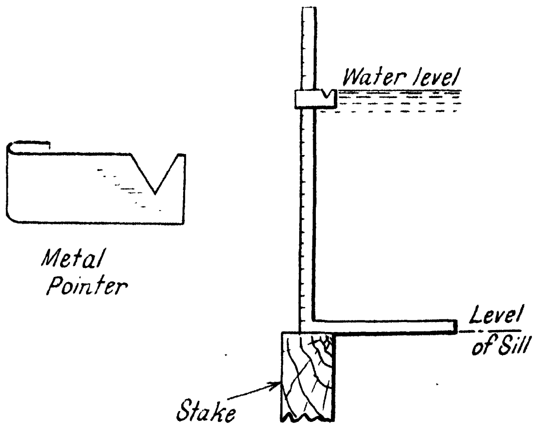


FIG. 79. SLIDING METAL POINTER AND SET SQUARE USED AS GAUGE

sill of the gauge, because the water level slopes at that point. It is much better to drive a stake as far upstream as possible; or where a wooden box is used it must be levelled so that the measurements may be taken from a step half-way between the last baffle and the sill. Baffles are necessary to reduce the fluctuations of flow created by the delivery into the box by the pump. These fluctuations occur even with an airlift pump. Measurements may be made by a small gauge, similar to that shown in Fig. 79, and having a point which can be set level with the water surface.

Water Towers or Elevated Tanks. Although the provision of a large service reservoir is apt to be costly, the expense is usually justified, especially if the main is a long one, since any failure of

the main would require considerable time to repair. Usually pumping is arranged to continue all day, so that the capacity need only be sufficient for, say, ten hours' supply. The site may have considerable bearing on the type of water tower or tank, and may determine whether it is to be of cast iron, or pressed steel plates, or reinforced concrete. Of the three types, a well-built reinforced concrete tower will require practically no maintenance, and periodical painting will not be necessary. It can be constructed so as to have a pleasing appearance, as, for instance, some of the circular types which can be seen up and down the country, and due to its height it can be used to bear an illuminated sign, advertising the name or product of a company.

When building a reinforced concrete tower it is advisable to have the inside lined with a cement screed to which has been added "Pudlo," or some similar material, to ensure that it will be water-tight when completed.

Height will depend on what pressure of water is required. A good head for general purposes is 75 ft., which gives a pressure of $32\frac{1}{2}$ lb. per in^2.

The cast iron tank of sectional form has advantages, especially for small sizes, as, in spite of rather high cost, it can be constructed with the absolute minimum of labour. Special angle plates and corner plates are used to join the bottom and sides, which are built up from rectangular plates having flanges machined and drilled to jigs, but the question of the cost of periodic painting must not be overlooked. The concrete tower certainly has a better appearance.

Service Mains. Wherever possible, well mains should be "ringed" (i.e. arranged on the principle of ring mains for electrical supply) with stop valves at appropriate positions, so that it may be possible to make a repair or small extension by shutting down only a short section of the main. Meters should also be installed in main supply and branch mains, to facilitate the costing of water consumptions to each department. A suitable consumption log should be kept, and the total weekly consumption entered on a chart in the Works Engineer's office.

Meters. There are several makers of water meters—the type of meter that should be employed depending on conditions. They may be operated either by means of a differential medium in the pipe line which would be connected to an instrument to indicate, integrate, and record (or any combination of these) the flow; or a positive type of meter may be used. If the differential device is employed, the Venturi tube or Venturi orivent tube orifice plate is connected to the instrument which will indicate, integrate, and record the flow. This type should be employed for metering feed water. A point to be remembered with differential meters is the loss of head occasioned by the differential medium in the main. The Venturi tube always shows the lowest loss of head, and in this connection the following

figures are of interest. The loss of head with the Venturi tube is $\frac{1}{4}$ of the differential head; with the Venturi orivent it is $\frac{1}{5}$ of the differential head; whilst with an orifice plate the loss of head varies with design; but for approximation it may be taken roughly as $\frac{1}{2}$ of the differential head. If a summation only is required, positive type water meters are best, as they give an extremely wide range of flow with an accuracy of within 2 per cent. They can be of the piston or rotary type such as those made by Glenfield & Kennedy, Frosts, or George Kents; the rotary type is more economical and takes less space for the smaller size mains.

Water Wastage. In all large works where water is used for cooling purposes there is a tendency to waste water. Wherever possible, this cooling water should be collected into a tank or forced back into the mains. Fig. 80 shows an arrangement for collecting water that has been used for cooling a large air compressor. As the compressor is too far from the elevated storage tank to make a circulatory system justifiable, the return water is forced back into the mains, a back-pressure valve preventing the same water from being used again for cooling. A sight-feed and a tell-tale alarm are arranged in the return circuit. The latter is well worth fitting in any case, as it enables the attendant to reduce the water supply to a minimum for a predetermined temperature for the water after cooling. The water flows back to a tank from which it is pumped back into the main by a motor-driven centrifugal pump controlled by a float switch.

In another case which may be cited, the cooling water from rubber machinery is returned to a tank and pumped back into the elevated storage tank. Not only does such an arrangement reduce the pull on a borehole or supply, but it is considerably cheaper than pumping from a borehole.

Hydraulic Machinery

The amount of upkeep required by hydraulic installations is largely dependent on the plant being laid out properly at the outset. Care must be taken to see that the accumulator and pump are of sufficient capacity to deal with peak loads, and that arrangements are made to obviate water hammer and shock in the pipe system and presses.

Where there are a number of presses—say in a "Bakelite" moulding shop—there is always the possibility of a large number of these machines coming into operation together; and whilst it is easy to calculate the required capacity for normal operation from the known area of ram and stroke of the various machines, plus a time study of the flow of work, allowance must be made for these peaks.

Where a new installation is being laid out and it is found that the simultaneous action of a number of machines is likely to occur,

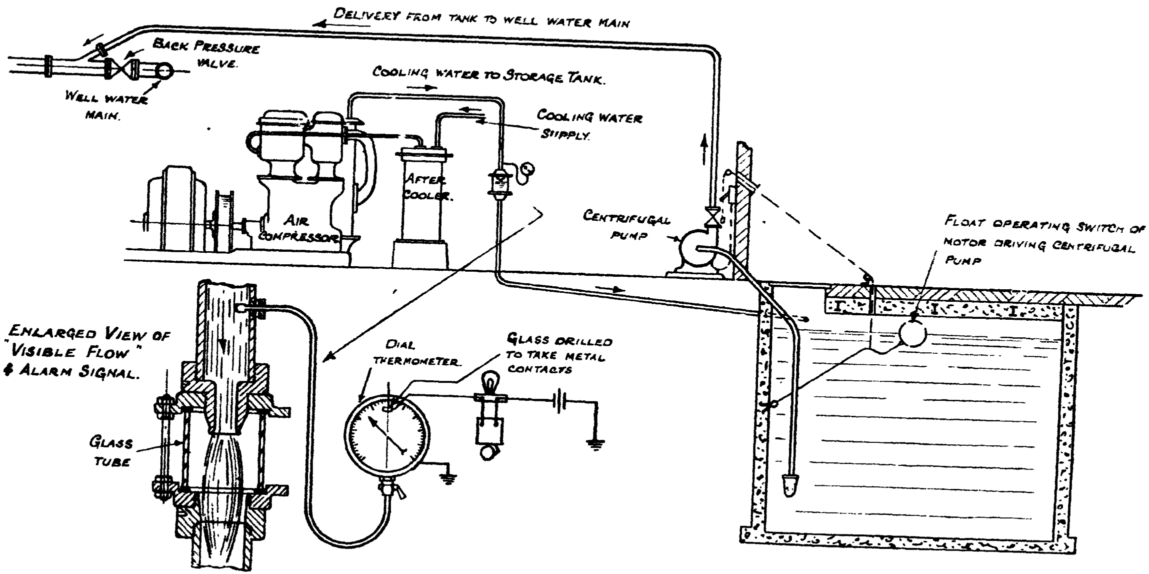


Fig. 30. Collection of Cooling Water from Compressor and Delivery into Water Main

it should be remembered that by increasing the pressure and reducing the size of presses, less water will be used.

Pipework. Delivery pipes from pumps to accumulator should be of ample size, and so should all return mains from machines.

It may be necessary to put a choke or throttling pipe of a smaller diameter in the delivery pipe from the accumulator, in order to retard the downward action of the ram and so prevent undue shock or water hammer being transmitted into the mains. A return system should always be arranged to conserve water and lubricant. All outside pipes should be suitably lagged against frost.

The method of coupling up the pipe flanges needs careful attention, and the latter must be of the correct design if leaky joints are to be avoided. The method which the author has found to be most satisfactory, is to form the joint on the ends of the pipe, the thread being turned off the end of one pipe to form a spigot as shown at *A* in Fig. 82, page 115. With this method the joint ring cannot blow out and will keep tight for years. The flanges should not be turned down to form a spigot, in an attempt to make the coupling easier to assemble, as it will be difficult for the fitter to make a good face on the female end of the pipe, and leakage may take place through the pipe threads.

Accumulators. The energy which a hydraulic accumulator is capable of storing is simply the potential energy of the ram together with that of the weight on it; it must therefore be remembered that an accumulator merely serves the same purpose in hydraulic machines as a flywheel does in reciprocating machines, and cannot be regarded as a considerable storehouse of energy in any sense analogous to an electric accumulator. It does also, however, serve to damp out fluctuations in the delivery pressure. It has a high efficiency, which may amount to 98 per cent of the energy required to "charge" it.

When installing an accumulator, the foundations must be of sufficient area and depth to ensure that settlement cannot take place; also the loading of the container must be evenly distributed; otherwise, due to the heavy load being thrown on one side of the ram, scoring will take place and packing replacement will become expensive. A cut-out or bypass to the pumps must be fitted to operate when the ram is at the top of its stroke. Where pressures above that on the main system are required for special machines an intensifier may be used.

Pumps are of the reciprocating plunger type, preferably three-throw, and must be of ample size to allow of a slow ram speed, otherwise excessive water hammer will take place. When the work is generally of an intermittent nature and the accumulator is well above the required capacity, it is advisable to arrange an automatic stopping device for the pump, an indicator being fitted above the pump showing the height of the accumulator ram; the pump can

thus be started again when the ram drops below a predetermined level. This is very useful on small plants. Fig. 81 shows an automatic belt shifter made for this purpose by the author some years ago.

Lubrication of the Water. When water is used as the operating medium, it is essential that some form of lubricant be added to prevent corrosion and pitting of rams and cylinders. Soap or glycerine is usually used, but a good soluble oil will give better lubrication. A mineral oil should not be used, as this may affect the packing. A special oil, such as Houghton's "Hydrolubric," which will blend

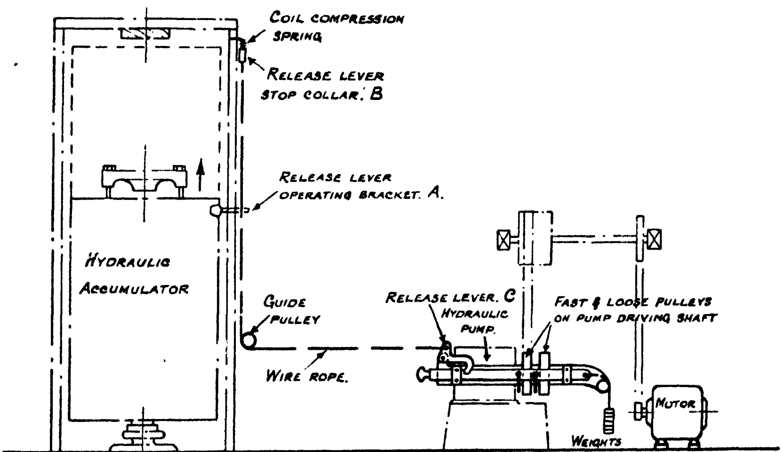


FIG. 81. KNOCK-OFF ARRANGEMENT APPLIED TO HYDRAULIC ACCUMULATOR

When lever *A* strikes stop collar *B*, release lever *C* is disengaged from belt-shifting bar and weights pull bar over, thereby moving the belt on to loose pulley

with either hot or cold water, can be used; 1 gal. of "Hydrolubric" will lubricate 1 000 gal. of water.

Packing is the most expensive item of maintenance on a hydraulic system and requires the most attention. Great care must be taken to see that all packings are properly fitted.

For all types of machines the "U," leather, when properly housed, usually gives the best service.

Bronze retaining rings should be used. Sometimes the retaining ring is turned down to form a support for the inside of the "U" packing and to force the lips of the "U" against the walls of the ram and cylinders. This is not advisable as, unless great care is taken in fitting, there is a tendency to set up undue pressure and thus rupture the bottom of the "U." If the ring is reduced in depth to allow of a small packing ring being inserted in the bottom of the "U," it will give much longer service.

For cold presses, leather "U" packing, such as "Vim" or Altringham leather, gives the best service; with hot presses, types such as the "Lion" patent "U" packing, which is composed of a special fabric reinforced with brass wire and impregnated with a water and heat-resisting compound, have a very long life.

For packing accumulator rams special "U" packings are usually supplied; whilst types such as "Lion Hard Glengarry" give good results, especially with worn rams.

Pressures. These vary from about 700 lb. per in². upwards, and it is difficult to lay down any hard and fast rule; 1 500 lb. per in.² is quite a common pressure for moulding presses. It must always be remembered that with a higher pressure the area of the ram can be reduced, thus using less water and reducing the necessary storage capacity. The total pressure of a machine in tons

$$= \frac{\text{Area of ram in in.}^2 \times \text{water pressure in lb. per in.}^2}{2\,240}$$

Pressure in lb. per in.² on material

$$= \frac{\text{Area of ram in in.}^2 \times \text{water (gauge) pressure, in lb.}}{\text{Area of material in in.}^2}$$

Wear on Rams. A new process called "Fescolizing," which greatly increases the life of rams and pump plungers, involves the electro-deposition of a thick coating of nickel or chromium on the surface of the plungers or rams. The coating usually adds 0·015 to 0·020 in. to the diameter and will last even better than steel; a very fine ground finish can be obtained, so the wear on the packing is greatly reduced and the parts are immune from corrosion and pitting. Nickel is generally used, but for very severe duties chromium will give slightly better results.

A temporary repair carried out by the author some time ago may be of interest. A cast iron accumulator cylinder cracked, necessitating its being put out of commission, and incidentally stopping the production of ebonite moulding. The accumulator was cut out of circuit and the connections were coupled up as shown in Fig. 82, the accumulator cut-out or by-pass valve being modified to operate as a safety valve. The breakdown occurred at noon on Saturday, but by employing the method explained, the shops were able to resume work on the Monday morning. It was only necessary to watch the operations of the presses to see that two were not brought up simultaneously, and with this precaution everything worked well until the new accumulator cylinder was installed.

Useful Water Data

Water is a chemical compound and consists of two volumes of hydrogen to one of oxygen. Its density is greatest at 32·2° F.,

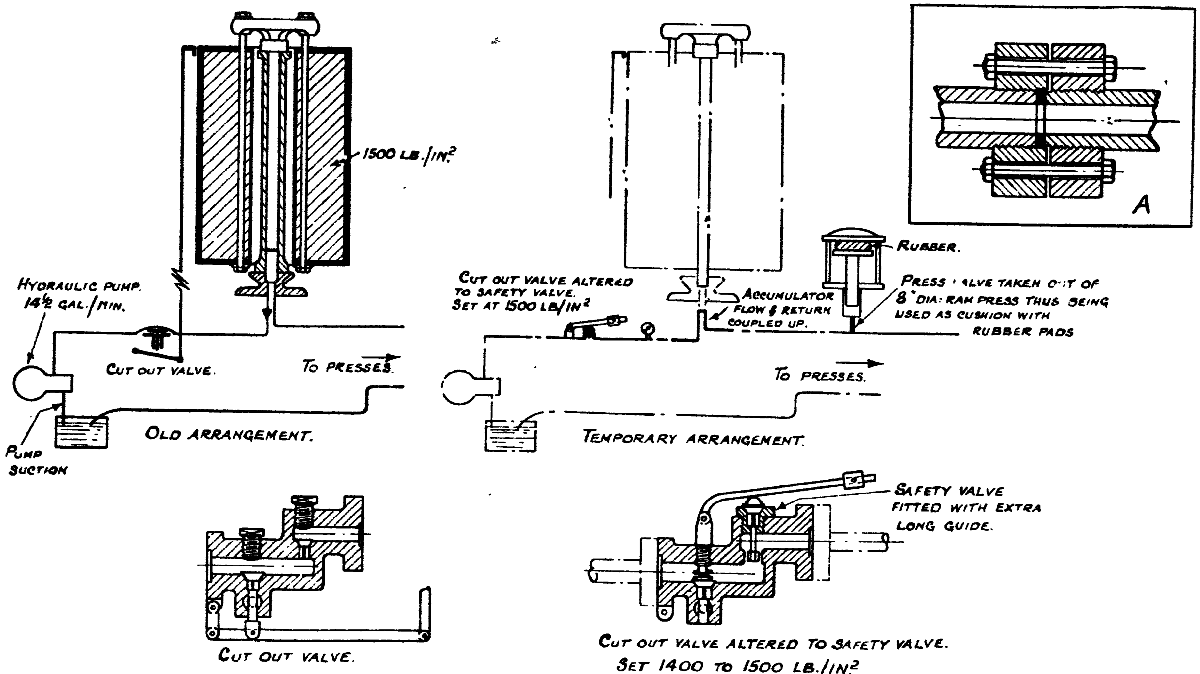


FIG. 82. TEMPORARY ARRANGEMENT EMPLOYED WHILST AN ACCUMULATOR WAS OUT OF COMMISSION

consequently when its temperature is reduced below this to freezing point it expands. Its compressibility is very slight; under an additional pressure of one atmosphere (14·73 lb. per in.^{2}) 1 000 volumes become 999·95 volumes.

Degrees of Hardness are given in grains per gallon or parts per 100 000, the former, generally referred to as the *Clark scale*, usually being employed in Great Britain. 1 gal. of water contains 70 000 gr.

To convert grains per gallon to parts per 100 000, multiply by 1·43.
To convert parts per 100 000 to grains per gallon, divide by 1·43.

$$1 \text{ Imperial gallon} = \begin{cases} 277{\cdot}46 \text{ in.}^3 \\ 10 \text{ lb. at } 62^\circ \text{ F.} \\ 0{\cdot}16 \text{ ft.}^3 \\ 1{\cdot}2 \text{ U.S. gal.} \end{cases}$$

$$1 \text{ ft.}^3 \text{ of water} = \begin{cases} 62{\cdot}35 \text{ lb. at } 62^\circ \text{ F.} \\ 6{\cdot}22786 \text{ imperial gal.} \\ 7{\cdot}476 \text{ U.S. gal.} \end{cases}$$

1 ton of water = 35·974 ft.^{3} at 62° F.

1 ,, ,, ,, = 224 English gal.

A column of water 1 ft. high exerts a pressure at base of 0·4335 lb. per in.^{2}

$$\therefore \qquad \frac{\text{Pressure in lb. per in.}^2}{0{\cdot}4335} = \text{Feet head.}$$

A column of water 2·31 ft. high at 62° F. exerts a pressure at base of 1 lb. per in.^{2}

$$\therefore \qquad \frac{\text{Head in feet}}{2{\cdot}31} = 1 \text{ lb. per in.}^2$$

Standard atmospheric pressure = 29·95 in. of mercury
= 33·9 ft. head of water
= 14·7 lb. per in.^{2}

Inches of mercury × 0·49 = Pressure in lb. per in.^{2}

Flow of Water in Pipes. (Hawksley's formulae.)

$$d = \frac{1}{15}\sqrt[5]{\frac{G^2 \times L}{H}} \qquad G = \sqrt{\frac{(15d)^5 \times H}{L}}$$

where d = Diameter of pipe in inches.
G = Gallons per hour.
H = Head of water in feet.
L = Length of pipe in yards.

FRICTIONAL LOSSES IN WATER PIPES. (Messrs. Kent's figures.)

$$h = \frac{6{\cdot}23\ V^2 l}{d} \div K$$

Where V = Velocity in ft. per sec.
l = Length of pipe in ft.
h = Pressure loss in inches of water.
K = Constant.

Values of K			
From	1– 2	in. diam.	= 800
,,	2– 4	,,	= 1060
,,	4– 8	,,	= 1600
,,	8–16	,,	= 2000

INCLINATION TO OVERCOME FRICTION IN PIPES. (Messrs. Kent.)

$$\frac{V^2 \times 2{\cdot}3}{d}$$

where d = Diameter of pipe in ft.
V = Velocity in ft. per sec.

VELOCITY IN PIPES. It is usual to allow for 3 ft. per sec. in water mains; for pumping mains this may increase to 5 ft. per sec.

APPROXIMATE WEIGHT OF CAST IRON WATER PIPES PER FOOT RUN. $2{\cdot}45 \times [(\text{Outside diameter})^2 - (\text{inside diameter}^2)]$ = lb. per ft. run (pipe diameter to be taken in inches).

Two flanges are approximately equivalent to 1 ft. run of pipe.

TANK CAPACITIES (all dimensions in feet).

Rectangular Tanks:—

Gallons capacity = Length × breadth × depth × 6·23.

Circular Tanks:—

Gallons capacity = Dia.^{2} × 0·7854 × depth × 6·23.

GAS

As with other services, all gas mains—painted their distinctive colour—should be arranged on the ring principle, with cocks fitted in suitable positions to allow of shutting off any one section. A weekly record should be made of all meter readings. As small gas meters are comparatively cheap when compared with those for steam and water, it will probably be possible to meter a larger proportion of branch services. An up-to-date layout plan of the gas mains should be kept in the Works Engineer's office.

Meters. Meter capacities are known by the number of *lights*, a light being equivalent to 6 ft.^{3} of gas per hour. There are two common types of meters, *wet* and *dry*.

WET METERS. For large installations a wet meter is more suitable, as it takes up less floor space. In this meter a drum, made up of four compartments, is mounted on a hollow shaft through which

the gas enters, and is submerged in water to a little above its axis. The compartments are so arranged that as the gas enters each compartment it forces the water out, thus causing the drum to rotate.

A new compact type of wet meter has recently been put on the market in this country and is called the "B-M" meter. The reports of this instrument are very satisfactory and supply authorities are

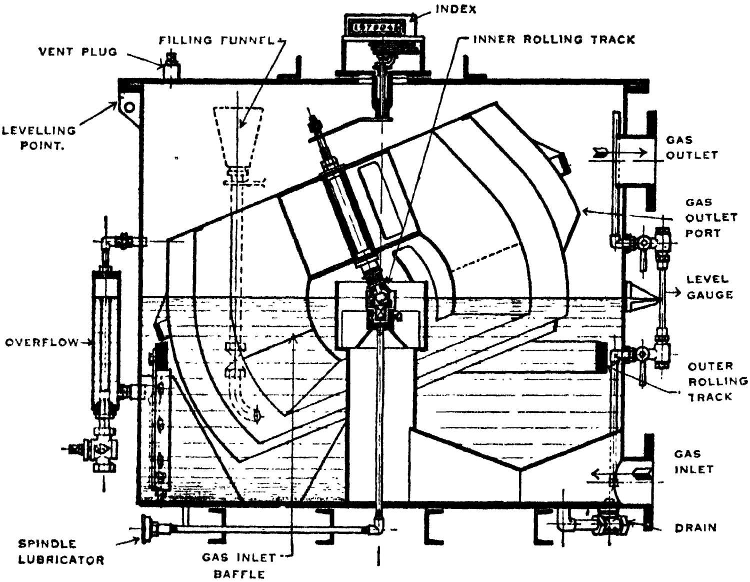


FIG. 83. SECTION THROUGH "B-M" GAS METER
(*W. C. Holmes & Co.*)

recommending it to big consumers. It differs from the usual type in that the drum, inclined at an angle, is mounted on a vertical hollow shaft, through which the gas enters. The action of this meter somewhat resembles that of a cycle wheel, running round a circular track; the drum being pivoted in the centre, and rolling around a track which gives it an inclination of about 30°. This rotation is transmitted to the counter and is positive in its action. The operation will be readily understood by referring to Fig. 83, which shows a section of this type of meter, as made by Messrs. Holmes of Huddersfield.

DRY METERS. There are several types of these meters. For supplies up to 400 lights, the *bellows* type is perhaps the cheapest. *Positive displacement meters* are used where great accuracy is required, the gas operating two impellers (somewhat similar to a

drum pump), as in such types as the Holmes "Connersville" meter. Accuracies up to 99·95 per cent have been attained by these meters on test. *Rotary* meters form another type; these are operated by a full flow of gas over a fan, and are usually accurate for flows between 10 per cent and 100 per cent of rated capacity, but should

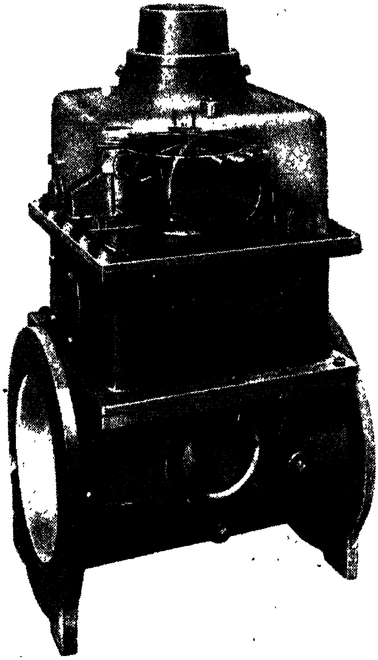


FIG. 84. PHANTOM VIEW OF SHUNT GAS METER
(George Kent, Ltd.)

not be used for flows below 10 per cent, as inaccurate readings will result.

A meter that is rapidly becoming popular for inside use in works is the Kent shunt gas meter, a phantom view of which is given in Fig. 84. It has a guaranteed accuracy of $\pm$ 2 per cent over a range of 1 : 10, with an overload capacity up to 100 per cent. Its chief features are low cost and small size for the class of metering it will do, and it is simple and very accessible. Cleaning nozzles are fitted if crude gas is to be metered. This meter is a counter meter only; if a record is required a balanced recorder can be used, or if an indicator is required a curved tube manometer should be employed. Fig. 85 shows an arrangement embodying these three meters.

The Therm. To-day, gas is sold on the therm basis; that is, it is bought on its calorific value instead of per 1 000 ft.^{3}. A therm is equivalent to 100 000 B.Th.U.; therefore, the equation to convert cubic feet to therms is as follows—

$$\text{Therms} = \frac{\text{Ft.}^3 \text{ consumed} \times \text{declared calorific value}}{100\,000}$$

The declared calorific value is usually between 450 and 560 B.Th.U. per ft.^{3} and has to be maintained by the supply authority.

Gas Pressure. The gas pressure should be as nearly constant as

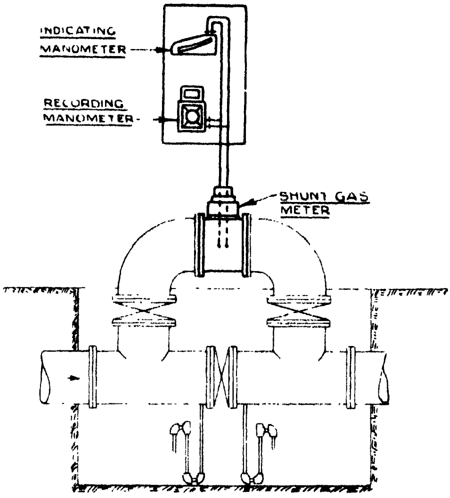


FIG. 85. SHUNT GAS METER SHOWING FITTINGS AND RECORDER
(*George Kent, Ltd.*)

possible, since variation will affect the temperature of furnace and other equipment which is gas-heated. Where a variation takes place due to demand, extra auxiliary mains should be installed, or better still, the diameter of the existing main should be increased, always remembering that two pipes of equal size will have less than half the carrying capacity of a new main of twice their diameter. Where the internal mains are too small, a booster can be fitted near the meter outlet to increase the volume delivered through the existing pipes, in which case it is advisable to fit a gas governor at each appliance.

Gas Governors. Most appliances can be operated with a natural draught and gas at town's pressure, and as mentioned above, it is essential that the gas pressure should remain constant if uniform heating is to be maintained; to ensure this, a gas governor should

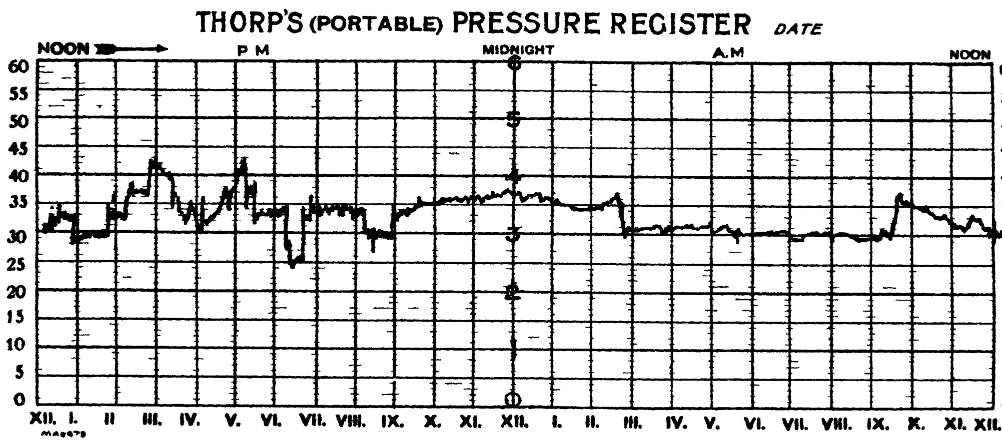
be installed. These governors are very efficient and the charts in Fig. 86 furnish a comparison of actual pressures with and without a governor. The ideal arrangement is to install a small governor to each appliance in preference to one large governor on the gas main. There are several good makes of governors on the market. The governor consists essentially of a valve whose movements depend on the outlet pressure; any increase in the outlet pressure above a predetermined value causes the valve to close. The outlet pressure is therefore allowed to fall until it reaches the desired amount. In practice, governors are commonly fitted with a weighted diaphragm, connected to the spindle of the actual valve controlling the gas inlet; the movement of the valve is thus dependent on the gas outlet pressure and on the weight attached to the diaphragm. There are two chief classes of such governors: (1) those in which fixed weights are attached to the diaphragm; (2) those in which these weights are variable. In the latter class, variation is effected by providing the governor with a removable cover so that more or fewer weights can be placed on the diaphragm.

It must be borne in mind that to secure the most accurate governing, the flow must be reasonably near the optimum consumption. Thus, if the rated maximum for a governor is 60 ft.^{3} per hour, it is unsuitable for rates below about 15 ft.^{3} per hour, or 25 per cent of the maximum rating.

Gas Main Sizes. Table 7 gives capacities in cubic feet per hour for different straight lengths and sizes of pipes, and is based on a specific gravity of 0·60. Where the specific gravity varies, the necessary correction to the rate of flow given in the table can be simply arrived at by adding 1 per cent for every 0·01 below a specific gravity of 0·6, and vice versa. The allowance for bends is given in Table VIII.

Premixed Gas and Air. Where there is a large consumption of gas for heating melting furnaces and other equipment where the flame is open, an automatic gas and air mixing apparatus is worth consideration, as savings in gas consumption up to 25 per cent are claimed in some cases. In this system the air and gas are mixed in definite and correct proportions to form a perfect combustible fuel, the pressure being kept constant irrespective of the fluctuations in the gas supply.

Surface Combustion. For enamelling ovens, etc., where burners of the Bunsen type are used, considerable savings in gas consumption can be made by replacing these burners with Cox combustors, such as the "Ignite" combustor. It is generally recognized that the most economic method of utilizing the heat value of any combustible gas is by surface combustion. These combustors are composed of a cellular refractory medium, the sizes of the cells gradually becoming smaller as they reach the surface. Air, coming from a small fan or through a reducing valve from the compressed air main, is fed to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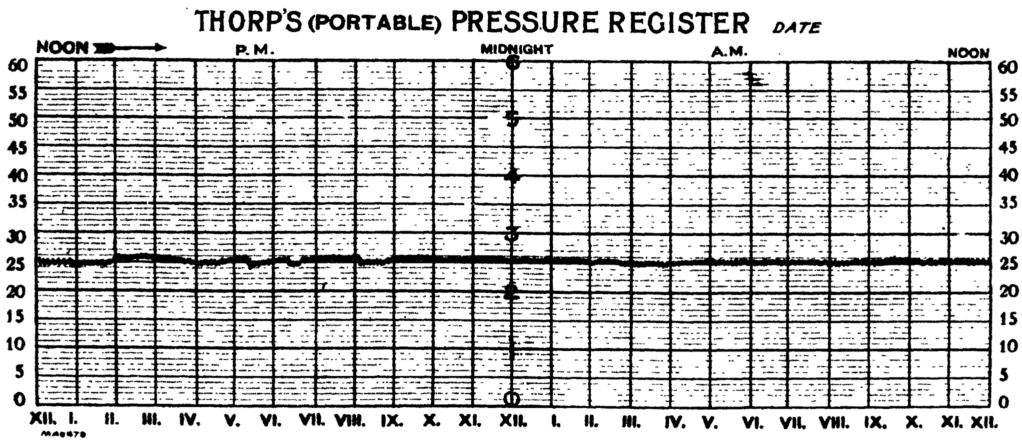


(b)

FIG. 86. CHARTS SHOWING REGULATION OF GAS PRESSURE

(a) Without governor (b) With governor

(*Coventry Gas Department*)

TABLE VII

Gas Main Sizes

Capacities in ft.^{3} per hr. with 3/10 in. Water Gauge Pressure Drop between Ends of Straight Pipes. Specific Gravity 0·60.

Length in Feet	Diameter of Pipe in Inches								
	1	1½	2	3	4	6	8	10	12
10	415	1 325	2 420	7 000					
20	300	940	1 725	5 610	10 200				
30	240	770	1 430	4 400	8,420				
40	210	680	1 225	3 490	7 280				
50	190	600	1 115	3 145	6 580	22 600	46 000	82 000	128 000
60	170	550	1 025	2 875	6 050				
70	160	510	960	2 670	5 635				
80	150	475	900	2 480	5 250				
90	142	450	850	2 360	5 000				
100	135	440	830	2 280	4 840	16 000	32 600	58 000	91 500
150	112	350	670	1 810	3 905	13 000	25 800	47 500	74 500
200	90	300	580	1 540	3 385	11 300	23 000	41 000	64 500
300	75	240	470	1 220	2 720	9 250	18 700	33 600	52 500
400	62	205	410	1 025	2 285	8 000	16 300	29 000	45 500
500	50	175	360	870	2 000	7 150	14 500	26 000	40 700
600	45	160	320	755	1 790	6 500	13 300	23 700	37 200
700	40	140	300	665	1 655	6 050	12 300	21 900	34 400
800	35	130	280	625	1 560	5 650	11 500	20 300	32 300
900						5 300	10 800	19 400	30 400
1 000	30	120	250	530	1 350	5 100	10 300	18 400	28 800

TABLE VIII

EQUIVALENT LENGTHS OF STRAIGHT PIPE TO ALLOW FOR BENDS AND TEES

Dia. of Pipe	Addition to Overall Length of a Pipe (in Feet) for Increased Resistance		
Inches	Elbows	Tees	90° Bends
$\frac{1}{8}$ to 1	2	2	1
1 to $1\frac{1}{2}$	3	3	$1\frac{1}{2}$
2	5	5	2
3	8	8	3
4	13	13	4
6	20	20	6
8	34	34	9
10	41	41	14
12	50	50	17

the burner together with the gas, and burns over a large surface area without flame, a red incandescent heating surface being obtained. This method is smokeless, clean, and enables a more uniform heat in the oven to be obtained; thus, apart from the saving in gas, this system has much to recommend it. If the air is taken from the supply main, a sensitive back-pressure valve must be inserted in the main to prevent the gas from getting into the air main.

Thermostatic Control. Thermostatically controlled gas valves should be fitted to all types of heating ovens, as this in itself will effect a considerable economy in gas consumption, apart from keeping a uniform temperature. There are three chief means of controlling temperature in furnaces: (1) thermostats employing the expansion of liquids; (2) those employing the expansion of solids; and (3) those employing thermo-electric effects.

(1) A simple type, using liquid expansion, consists of a bulb containing a liquid with a high coefficient of expansion. Toluene is suitable; it is connected from the bulb to a column of mercury so that the toluene, by expanding, will make the mercury rise and reduce the fuel supply by closing a gas seal. The drawback of this type is its lack of sensitivity.

(2) Thermostats using the expansion of solids are the rule. The principle employed is that of the differential thermal expansion of

two components, one having a high coefficient of expansion, e.g. steel, copper, or brass, and the other a low coefficient of expansion, e.g. porcelain, silica, or invar (36 per cent nickel steel). For temperatures up to 510° F. a brass-iron combination is satisfactory, but up to about 1 000° F., steel-silica is better, as fatigue does not develop so markedly. In the former type an expansion tube of brass forms a sheath for the invar rod. A spring holds the upper portion of the valve seating against the rod, adjustment being provided by rotating the screwed cap which houses the spring. To avoid the possibility of extinguishing the flame accidentally, a bypass is provided. Additional sensitiveness can be obtained by using a valve with a knife-edge seating. The valve will open when there is only a low pressure above the diaphragm, but when that pressure rises to that of the incoming gas, the valve will close.

(3) The principle of the thermo-electric pyrometer can be made to control gas flow by means of a system of relays. A "chopper" bar is arranged so that it may descend on one of three switches, according as the temperature concerned exceeds, equals, or falls short of the predetermined temperature. Any divergence from the predetermined temperature causes the switch to close a circuit operating a reversing electric motor. The motor is coupled to, and therefore controls, the gas inlet valve. A system of red, white, and green lights indicates whether the temperature is above, equal to, or less than the set temperature. If the motor operating the valve is geared down, a very fine adjustment can be secured.

General. Care must be taken, in choosing thermostats, to select materials capable of enduring the working temperatures for an indefinite period. The distance the thermostat dips into the furnace or open pot is also important. In the latter case, the depth of the liquid in the pot may vary, and this will affect the temperature on which the operation of the thermostat depends. The amount of metal in the thermostat rod affects the sensitivity of the thermostat; if this is small, the rate of response to temperature changes will be correspondingly rapid. The outer tube is therefore best made as thin as possible, and preferably without a steel protecting sheath.

Industrial Gas Equipment

Uniformly Heated Ovens. Where small ovens are required for drying or baking small pieces of manufactured apparatus at low temperatures (up to about 300° F.), and where it is essential that a uniform heat shall be maintained throughout the oven, the author has found a gas-heated oil-jacketed oven, as shown in Fig. 87, very satisfactory.

Oven Furnaces. Gas-heated furnaces, as shown in Fig. 88, are widely used for carburizing, reheating, and annealing purposes. Working temperatures up to 1 000° C. can be obtained with this type of furnace, and automatic temperature control equipment can

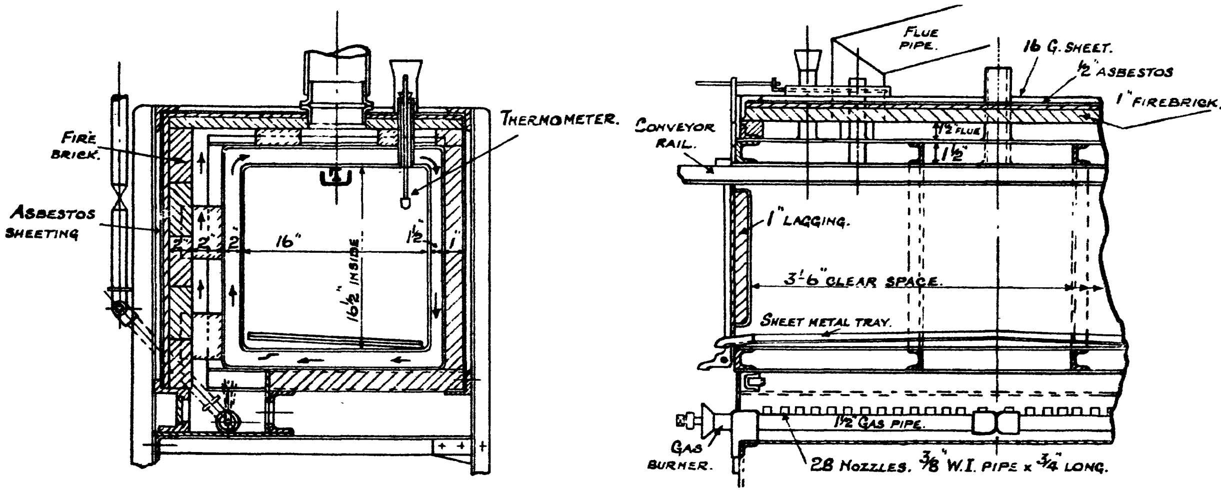


Fig. 87. Oil-Jacketed Gas-heated Oven

be fitted. The furnace operates with natural draught and gas at town's pressure, approximately 3 in. water gauge.

Recuperators are fitted in the furnace, and the air for combustion gathers heat from the discharging flue gases by these means. The furnace hearth is heated underneath; and for normal working with average loads, the hearth should last about four years before being replaced. The old floor tiles can be taken out and the new ones fitted without disturbing the furnace walls and roof. Scotch firebrick tiles are preferred for hard wear, but normally Stourbridge tiles give satisfaction.

Troubles experienced with this type of furnace are usually limited to blocked burner passages, and this is a rare occurrence if guard tiles are fitted on each side of the furnace hearth. Flue troubles can be avoided by fitting suitable cowls to break the flue pull and arrest downdraughts. These cowls are clearly shown in the illustration. They can be connected to a vent carried through the roof, or to trunking and an exhauster fan.

High-speed Steel Furnaces. For hardening cutters, dies, and tools, double-chamber furnaces are used, the preheating chamber at 800° C. and the final temperature chamber 1 240° C. For the best results the work should be heated to the final temperature very quickly in a non-oxidizing atmosphere. Air at 1 lb. per in.^{2} and gas at town's pressure are used on this type of furnace.

Air Heaters. Controlled hot air is being used for a wide range of processes, particularly for drying purposes. The circulated hot air carries off the moisture, and the moisture-carrying capacity of air increases enormously with increase in temperature. Gas-fired air heaters are made in a complete unit with fan, etc., and remote thermostatic control is fitted to give automatic temperature control of the work being treated.

For processes requiring heated fresh air only, the gas-fired heater is designed to discharge the flue gases separately. Gas is burnt inside a series of gilled tubes and the air to be heated is passed around the tube. This heater is known as the *indirect type*. With the *direct type* the gas burners are located in the air-heating chamber, so that the small amount of flue gases is mixed with the hot air. The latter type of air heater has proved successful for core drying and mould drying, small stove-enamelling work, and for ageing aluminium alloys, whilst the indirect type is used for large stove-enamelling work, drying colour work, and foodstuffs.

Pot Furnaces. Pot furnaces heated by gas are used for melting aluminium alloys, brass, gunmetal, copper, nickel, and soft metal such a lead, etc., also for cyanide, salt, lead, and oil baths for heat treatment purposes. The brick setting is designed to follow the shape of the pot and only a small space is allowed for combustion. A drain hole is provided for, and in some cases space is left to allow for the bulging of the pot. Natural-draught gas burners are only

FIG. 88. GAS-HEATED FURNACES

(Coventry Gas Department)

fitted for the low-temperature pot furnaces, pressure burners being used for the other furnaces.

Hot Water Tanks. Settings for gas-heated tanks used in plating shops, etc., give the most efficient results when designed to surround the tank entirely. A small space of 1½ in. to 2 in. is left between the tank and the insulated surround, and the hot gases from the burners pass round this space before being discharged to the flue. Automatic temperature control can be provided by means of a thermostat.

For tanks containing heated solution such as that used in rust-proofing, etc., gas burners should not be placed under the tank, but should be located at the sides of the tank or inside heating coils which pass through the tank. Should the burners be used under the tank bottom, there is a tendency for the bottom plate to be burnt through, owing to a film of deposit from the solution collecting on the tank bottom.

Maintenance of Equipment. Whilst properly designed equipment should operate free of trouble, a knowledge of how to deal with faults will be useful. Shortage of gas at the appliance sometimes occurs, and this is usually found to be due to the internal gas pipes being overloaded. The section of pipe where the greatest pressure drop occurs can be found by taking pressures at different points along the line; this section should be increased to a larger size. Should it be possible to operate the equipment at a lower gas pressure, a gas governor can be fitted at the appliance and set below the minimum pressure.

For natural-draught Bunsen burners, approximately one-third of the air required for combustion is drawn through the air hole inside the burner as primary air, another two-thirds being required as secondary air to complete combustion. Sometimes the secondary air is excluded from the appliance, resulting in incomplete combustion. Another fault which is easily detected is a choked flue passage, as the gas flames are stifled and float about when the flues are blocked or too small. The remedy for this is to make the flues large enough and to control them by means of a damper.

Troubles with remote control thermostats are usually confined to a leaky joint between the control valve and the thermostat. This connection is made with copper tube $\frac{3}{16}$ in. diameter, and should a small leak occur in this line the pressure is relieved instead of operating on the large leather diaphragm and closing the control valve.

In some cases the bypass gas consumption is set too high, and, whilst the thermostat closes the main gas supply, the temperature rise is not checked. The obvious remedy in this case is to set the bypass consumption to give scarcely enough heat for the job, thus allowing the thermostat to supply the additional heat as required and thereby ensuring a constant temperature.

The author has found it advisable to train a suitable maintenance

bricklayer (say the chargehand) to do all furnace repairs; whilst it may cost a little more in repairs for a short period, this will more than be repaid once the man becomes proficient. Refractories can be inspected by him and slight repairs made from time to time as they become necessary.

COMPRESSED AIR

Turbo-blowers and Turbo-compressors. Both turbo-blowers and turbo-compressors are designed according to similar principles, the difference between the two being quite arbitrary. For blowers, the compression pressure may be up to 30 lb. per in.^{2}; above this figure the machines are classed as compressors.

TURBO-BLOWERS are in effect centrifugal air pumps having several stages, the air passing through the eye of the first impeller and having its pressure increased whilst travelling to the periphery, after which it is led to the second impeller by means of guide-blades. Succeeding stages of compression are arranged similarly. The method of governing is based on the maintenance of constant speed, constant pressure, or constant delivery. A natural tendency for the impellers to move towards the suction side of the casing, due to unbalanced force acting on them, is counteracted by the use of thrust blocks or balance pistons, or by designing the blower as a double-flow machin

TURBO-COMPRESSORS, since they compress the air to much higher pressures than blowers, usually require some means for cooling the compressed air, as a considerable temperature rise may occur during the process. In some cases, the whole surface (except the impeller) is water-jacketed. Generally speaking, the larger turbo-compressors show the most marked economy over reciprocating compressors. The speed of rotation is decided by the capacity of the compressor and is generally highest for the smallest sizes. It frequently happens that the variation in demand is much greater for compressors than blowers, so that a high efficiency over a wide range of delivery is desirable. As with turbo-blowers, thrust blocks or balance pistons are necessary, unless a double-flow design is adopted. Governing is arranged by maintaining either constant speed or constant pressure. The principle of the Venturi meter is used in the Rateau constant-volume governor; a throat piece is fixed to the inlet pipe, giving rise to an increased air velocity and decreased pressure (actually a partial vacuum). A spring-controlled piston, with the atmosphere acting on one side and the partial vacuum on the other, carries a rod attached to a lever coupled to the speed-controlling mechanism of the prime mover or driving motor. Regulation is effected by the setting of a sliding weight on the lever. Any variation in the demand for the air delivered will cause a change in the partial vacuum under the spring-controlled piston, so that the lever will be moved and the speed of the driver will be suitably adjusted.

RECIPROCATING COMPRESSORS. Whilst turbo-compressors are mostly used where the requirements exceed 5 000 to 7 500 ft.^{3} per min., reciprocating compressors are more economical for the normal works and have a greater efficiency than the former. They may be of the steam-driven type, in which the steam and air cylinders are directly connected; or they may be driven direct-coupled to an electric motor, or through gears by a turbine if the exhaust steam is available.

They are usually of one or two stages. The two-stage machine is

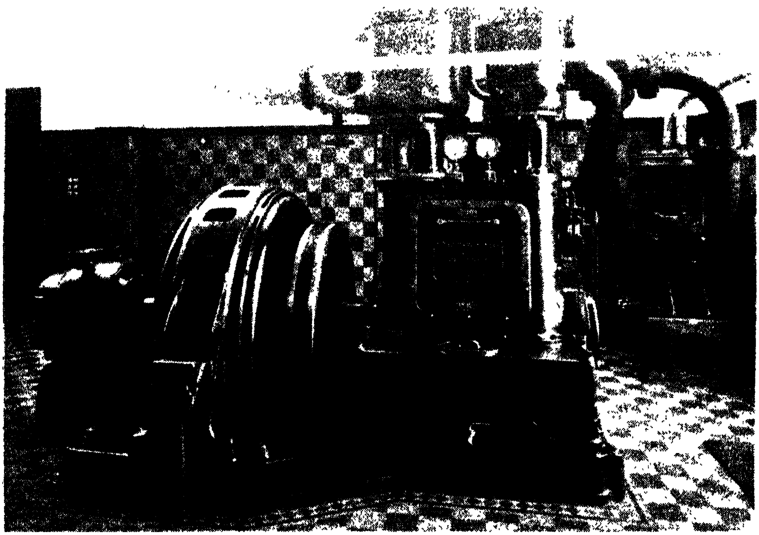


FIG. 89. BELLISS & MORCOM TWO-STAGE AIR COMPRESSOR, DRIVEN BY G.E.C. SYNCHRONOUS MOTOR
(*G.E.C.*)

the more efficient, as the single-stage takes more power and has higher air temperature to contend with. With the two-stage machine an intercooler can be fitted between high- and low-pressure cylinders.

When considering the installation of a new compressor, if the pressure required is about 100 lb. per in.^{2}, a two-stage machine with inter- and after-coolers is advisable. If it is possible to replace a number of small compressors with one large compressor of this type, considerable saving can be made in maintenance, oil, and attendance; a synchronous motor drive is also worth considering, as this will help to improve the power factor of the electrical load

and so effect a saving which may assist in getting sanction for the new plant.

With a two-stage compressor, having an output of 750 ft.^{3} of free air per minute, with inter- and after-coolers, the author has maintained an outlet temperature of 59° F. and avoided moisture and oil troubles. Fig. 89 shows this machine driven by a 140 h.p. G.E.C. synchronous motor.

Air Mains. The same arrangements of pipe layout, etc., as for water and gas, should be carried out. The troubles generally experienced in compressed air mains are due to oil and moisture.

Oil. Trouble from oil may arise from a number of causes, such as broken or worn piston rings, over-filling of the compressor crank

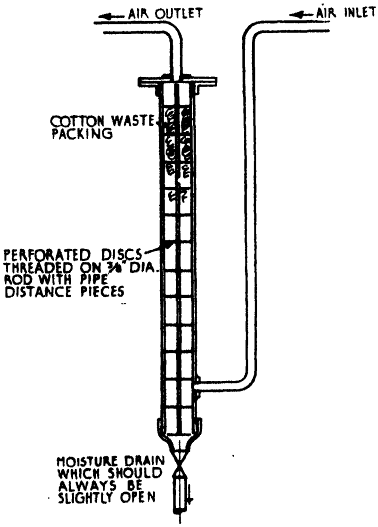


FIG. 90. AIR MOISTURE TRAP

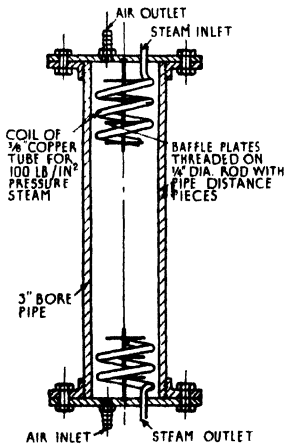


FIG. 91. STEAM COIL AIR HEATER

case, or general over-oiling; an inspection of the compressor will determine the cause.

Moisture. Trouble from this cause is especially prevalent in very humid weather and is due to the moisture in the inlet air being carried through the compressor. The air heats as it is compressed; when the air cools, this moisture is dropped in the pipe line. Where coolers are not installed with the compressor, and the receiver is adjacent to the compressor, this will always happen. If it is possible to move the receiver some distance away and arrange a fall in the pipes from the compressor, most of the moisture will drain to the receiver, which should be blown out frequently. Dips should also be arranged in the service mains and suitable draining legs or traps

provided. Where compressed air is used for paint spraying, an effort should be made to arrange a local air receiver on the job, and this should be frequently drained. Two methods of eliminating moisture troubles where spray guns are used are shown in Figs. 90 and 91.

Fig. 90 shows a moisture trap, and Fig. 91 a steam-heated air

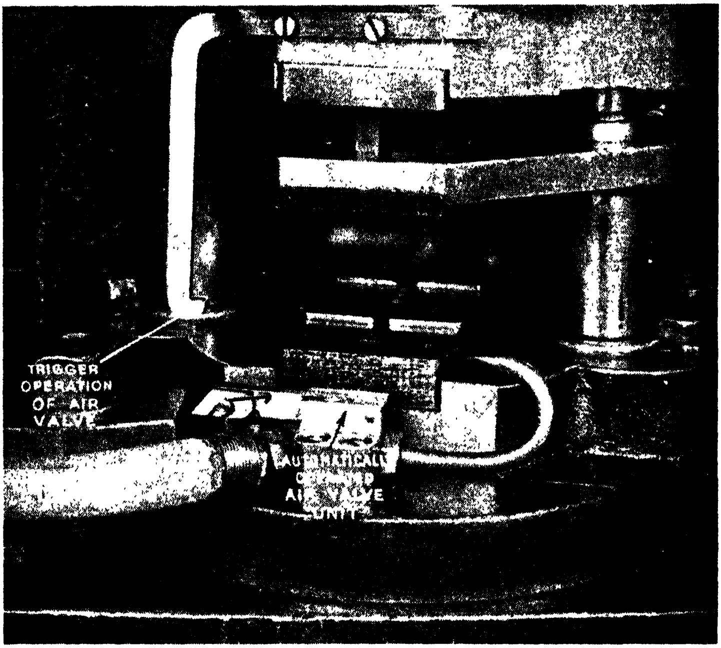


FIG. 92. AUTOMATICALLY OPERATED COMPRESSED AIR SUPPLY APPLIED TO PRESS TOOLS

(*G.E.C.*)

heater, both of which have given good results and can easily be made up by the Maintenance Department.

Another method of overcoming the moisture trouble is to install silica gel units, which should be in tandem, so that one unit can be re-activated by heating, whilst the other one is in use.

On paint-spraying units a combined transformer and filter forms part of the equipment. The cotton wool in the filter should be inspected each day and changed when necessary.

Air Receivers should be raised off the ground to allow of inspection of the underside; and suitable manholes provided for internal inspection. It is advisable to have them insured with the boiler

insurance company, who will then periodically inspect them. The explosion risk is just as great as with a steam receiver of the same pressure.

Under the new Factories Act, which came into force in July, 1938, all air receivers must be cleaned and examined or tested by a competent person at least once in every twenty-six months and a report entered in the General Register; an "Air Receiver" is taken to mean any vessel other than a pipe or coil and includes any paint, lacquer, or oil veessl which is operated by compressed air.

With compressed-air operated tools, continuous jets should not be used unless they are essential, as large savings can be made by fitting automatic valves to tools such as that shown on the press pressure pad in Fig. 92. All air pistols should have a spring trigger, so that the air is shut off when the pistol is released.

Clean Air. Where possible, suitable filters should be fitted on the inlet side of the compressor. A louvred box on the roof of the building in which the compressor is housed, with matting screens, makes a very good arrangement. An example of this sort is shown in Fig. 93. Birmingham Blind School make a close-woven matting suitable for this purpose. A nozzle for reducing the amount of noise may be inserted in the mouth of the suction pipe, as shown in the diagram. On small branch pipes where air has to be particularly clean, a Vokes filter is very effective.

Compressed air is being used more and more in industry to-day and when installing a new compressor it is advisable to bear this in mind and provide a machine of ample capacity. With the wide range of compressed-air operated tools—to mention a few: vices, lathe chucks, small portable drills, riveting hammers, and air presses —there is scarcely a manufacturing plant that cannot find new uses for compressed air, and manufacturers are always putting on the market new tools which can effect a saving if there is an ample supply of air.

To find the horse-power required to compress a given amount of air—

$$\text{H.P.} = \frac{144\ \text{NPV}n}{33\,000\ (n-1)}\left[\left(\frac{\text{P}_2}{\text{P}}\right)^{\frac{n-1}{\text{N}n}} - 1\right]$$

where N = Number of stages.

P = Atmospheric pressure.

P_2 = Absolute terminal pressure in lb. per in.^{2}.

V = Volume of air (ft.^{3} per min.) compressed, at atmospheric pressure.

n = Constant = 1·41 for adiabatic compression.

Air-flow Meters. An air-flow meter such as that manufactured

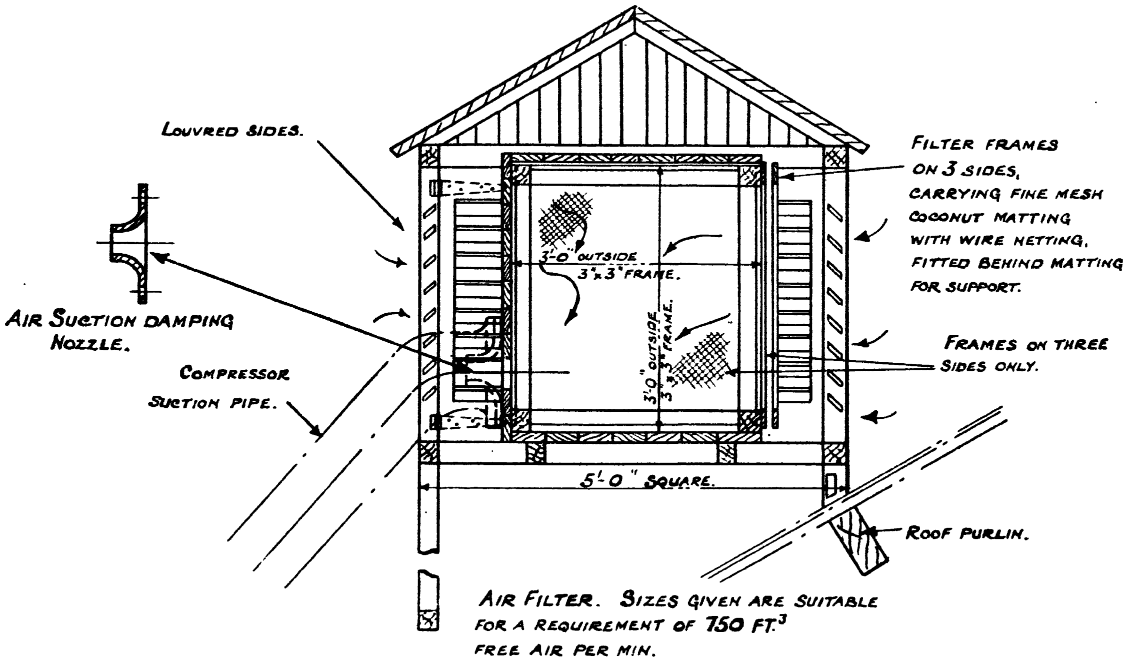


FIG. 93. AIR FILTER FOR AIR INTAKE OF COMPRESSOR

by Messrs. George Kent is suitable for measuring fluctuating quantities of air in the pipes supplying pneumatic tools, hammers, blast furnaces, etc. The action depends on the angle taken up by a swinging "gate," suspended in the pipe, so that the air impinges on it with a force varying with the demand being made on that particular pipe line at that moment. The swinging gate is connected by a hair spring to a pointer above the dial of the instrument. A dashpot is provided to damp out any pulsations that might affect the indicator. The angle of the gate to the direction of the air flow, and hence the reading on the dial, is directly proportional to the flow itself. A pressure drop of about $\frac{3}{4}$ lb. per in.^{2} exists across the indicator at full load.

Vacuum Pumps and Systems

In recent years the use of vacuum plant has increased enormously for a wide range of purposes, and as this class of plant presents special problems, no modern textbook would be complete without some reference to it. The radio and telephone industries use special vacuum plant in the making of important components.

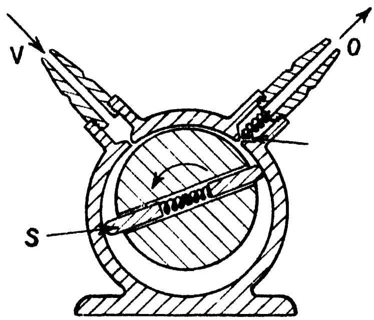


Fig. 94. Rotary Oil Pump
O. Outlet. S. Scraping vane. V. Vacuum.

It is frequently the practice, where high-vacuum processes are concerned, to produce a "rough" preliminary vacuum varying in pressure from 20 mm. to $\frac{1}{100}$ mm. of mercury. This is followed up by a final exhaustion by high-speed pump. This initial exhaustion is produced by a "backing" pump, which is usually a type of mechanical oil pump. The speed of a pump is given in terms of the volume of gas exhausted per second, measured at the pressure produced by the pump; it is clear, therefore, that a backing pump need only work at a fraction of the speed of the high-vacuum pump which it is backing.

Oil Pumps. Oil has long been used as an airtight seal between the moving parts of pumps. There are two chief classes of oil pumps: reciprocating and rotary. Both inlet and outlet sides should be provided with drying equipment, as oil can hold considerable amounts of both water vapour and air in solution; these are given out under reduced pressure.

The Geryk pump is of the reciprocating type. The piston, which moves vertically, is provided with a leather cup; above it is a pool of oil which moves up and down with it, forming a

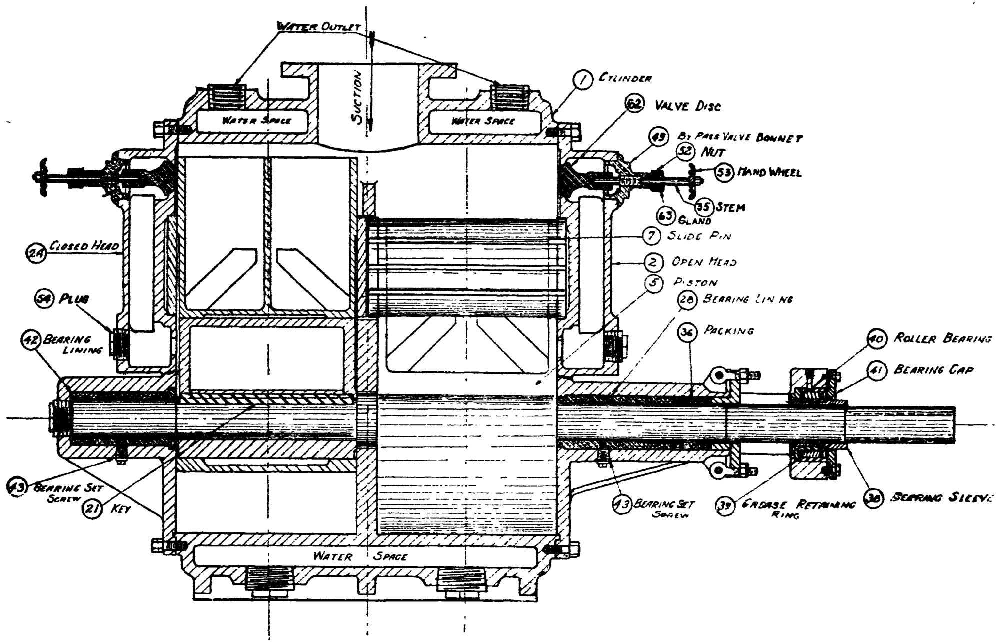


FIG. 95. KINNEY HIGH-VACUUM PUMP
(General Engineering Co. (Radcliffe), Ltd.)

seal. At the top of the cylinder is a spring-controlled valve, which opens when the piston approaches the highest part of its stroke; the entrapped gas leaves the cylinder through this valve. Two-cylinder pumps are also made and can be connected in series if low pressures are desired, or in parallel if the volume of gas to be dealt with is large.

Rotary oil pumps generally work on the "scraping vane" principle; the principle itself has long been understood, but the first

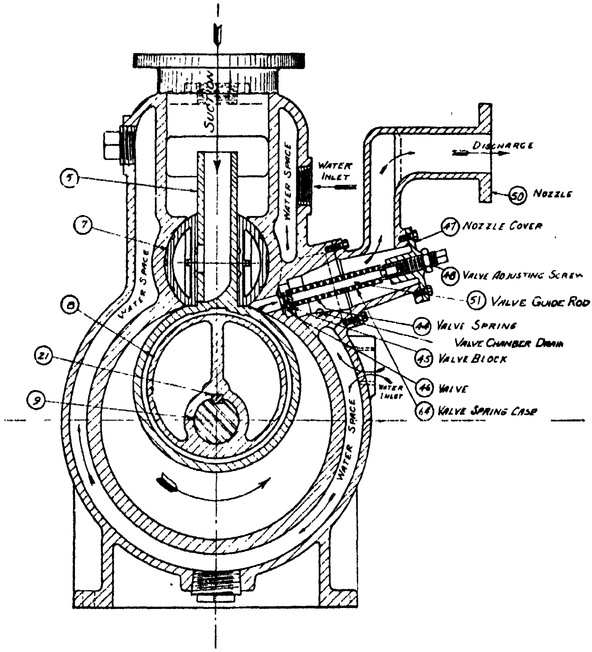


FIG. 96. KINNEY HIGH-VACUUM PUMP
(General Engineering Co. (Radcliffe), Ltd.)

modern application was probably made by Gaede in 1907. A revolving horizontal cylinder of solid steel is arranged with a larger cylindrical casing of bronze, but not concentric with it (Fig. 94). Small helical springs placed in slots in the cylinder keep two vanes, which are free to slide in and out of these slots, continually pressed against the inner surface of the casing, scraping against this surface as they rotate with the cylinder. During each revolution, portions of air are drawn from the inlet port, trapped by the scraping vanes, carried round the casing, and passed out through the outlet port.

The "box" pump of this type is entirely immersed in oil, and is largely used in electric lamp and radio valve factories as a preliminary or backing pump. Starting from atmospheric pressure, a vacuum of $\frac{1}{100}$ mm. can be obtained.

High-vacuum Pumps. Probably the best known and most widely used pump is the "Kinney" High-vacuum Pump. Figs. 95 and 96 illustrate this type. Since it does not need to work from a preliminary "rough" vacuum, a backing pump is not required.

Essentially, the pump consists of a shaft (9) on which are mounted two eccentrics or cams (8) set 180° apart. On these cams are mounted pistons (5), each with a hollow arm or slide which works freely in a slide pin (7). All these parts are carefully finished all over, and fit snugly in the pump cylinder and between the two heads (2) and (2A).

In operation, the shaft rotates in the direction indicated by the arrow, carrying the cams round with it. The cams impart an oscillating motion to the pistons, which thus act as plungers moving vertically. The plungers tend to create a vacuum by withdrawing air from the space above them (marked "suction" in Fig. 96). The air thus withdrawn passes into the casing containing the cam; the rotation of the cam carries this air before it, somewhat on the principle of the scraper-vane pumps, and expels it, through the discharge valve (46) and the nozzle (50), to the atmosphere.

To prevent any backrush of atmosphere air to the suction pipe, the pump is arranged so that just before the piston attains its highest position (as in Fig. 96), the slots in the hollow slide are completely closed by the slide pin. Since these slots themselves form the passage through which air is drawn into the cylinder, the action of an effective mechanically-operated suction valve is thus achieved.

A study of the diagrams will show that the re-expansive clearances have been reduced to a minimum, a condition essential to the high volumetric efficiency and high final vacuum obtained.

No internal packing is used. The pistons and other parts which must be airtight are oil-sealed by a unique method, whereby only the amount of oil necessary to prevent leakage is admitted. This amount is small, and at each revolution all surplus oil is discharged to the separator; thus no flooding of the pump is possible while it is in operation, and consequently there is no excessive churning or resultant heating of the oil.

Oil is discharged from the pump along with the air into an oil separator of sufficient capacity to allow any condensed moisture to settle out, after which the oil is used over again. This process is continuous and automatic.

Sealing oil is carried from the separator to the pump and stuffing box through suitable piping, needle valves being provided to regulate the amount of oil flowing into the pump. A plug cock is

provided for shutting off all sealing and lubricating oil when the pump is shut down.

The foregoing description applies specifically to the "D.V.D." type of pump, which is duplex. The "V.S.D." type is similar, except that it is of the "simplex" pattern, there being only one cam and piston.

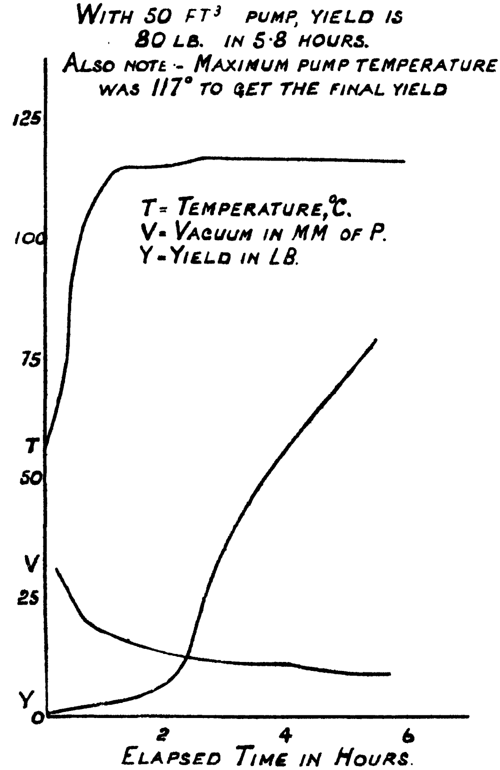


FIG. 97. PERFORMANCE CURVES FOR HIGH-VACUUM PUMP

Fig. 97 gives data relating to the performance of a Kinney high vacuum pump.

In the manufacture of radio valves, high-vacuum pumps are essential, and when the valves are made on rotary machines, or on manifolds, it is imperative that complete exhaustion of air shall take place. It is also necessary to have large-size pumps for this class of duty in order that many valves may be treated simultaneously; and another reason is that, if one of the glass bulbs should prove to be defective, the rest of the valves under exhaustion

will not be damaged, because the pump will have ample capacity to exhaust the leakage and maintain the vacuum.

The Kinney pump is universally used for this class of work, but in many cases the final finishing process is accomplished by means of special, and often secret, methods, such as flushing with special gases. By putting pumps in series, vacua as low as 0·5 micron (1 micron = $\frac{1}{1000}$ of 1 mm.) above perfect vacuum can be obtained.

Special vacuum plant is also used for transformers, field coils,

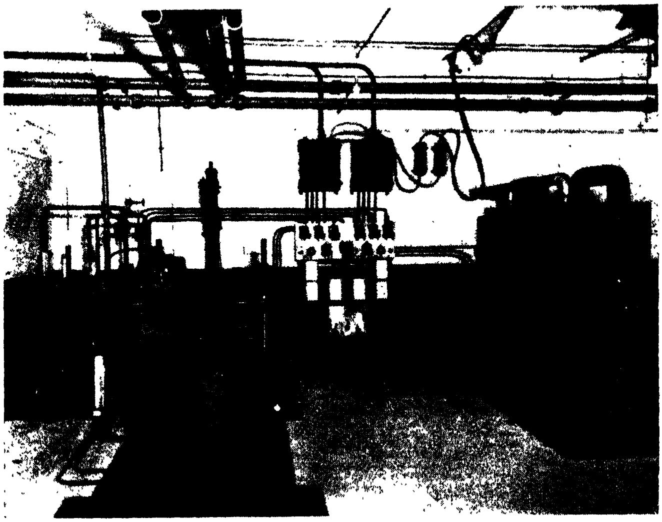


FIG. 98. ELECTRICALLY OPERATED OIL-HEATED HIGH-VACUUM PLANT
Showing impregnators, ovens, and stoves
(*General Engineering Co. (Radcliffe), Ltd.*)

chokes, etc. These are usually constructed of tightly-wound fine enamelled wire interleaved between layers of special paper. A typical plant for this purpose is shown in Fig. 98. This plant will deal with as many as 10 000 transformers per day, and the windings are preheated, dried under high vacuum, and impregnated under pressure with an insulating compound. The plant illustrated impregnates with a bitumen compound, having a viscosity specially suited to the work; it is forced into the windings at a temperature of approximately 300° F.

The molecular pump introduced by Gaede and improved by Holweck, and shown diagrammatically in Fig. 99, is designed to produce high vacua from backing pressures of from 20 to $\frac{1}{100}$ mm. It depends upon the frictional drag which a rapidly moving surface can exert on a gas. A cylinder revolves at high speed inside a

closely-fitting fixed casing having inlet and outlet connections. The moving surface of the cylinder drags the gas from the inlet to the outlet port. The ratio of the inlet to the outlet pressures varies with the circumferential speed of the cylinder, so that with a high peripheral speed and a low backing pressure, it is possible to obtain a high degree of vacuum. In fact, pressures as low as one-millionth of a millimetre can be attained with a cylinder speed of 12 000 r.p.m. and a preliminary backing pressure of $\frac{1}{100}$ mm.

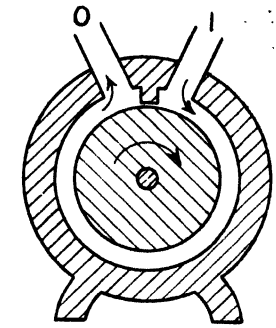


FIG. 99. MOLECULAR PUMP

I. Inlet connection to vacuum
O. Air outlet

Another general type is known as the *mercury-vapour* pump. Mercury is contained in a boiler and, on being heated, gives off particles of vapour which flow down a tube leading to a condenser and backing pump. A branch line from this tube is connected to the high-vacuum line. At the upper end of the tube the vapour pressure is high enough to prevent air from flowing back against the stream of mercury vapour.

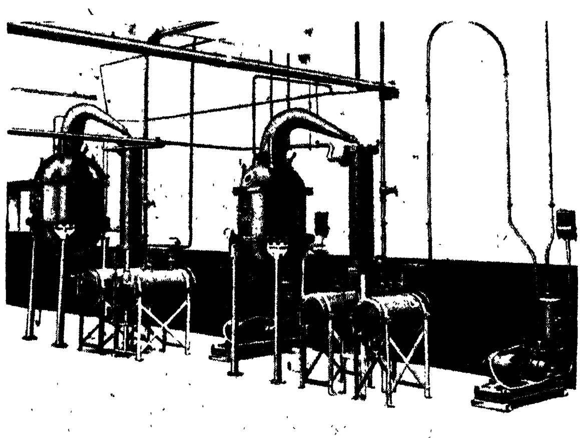


FIG. 100. TYPICAL LAYOUT OF DISTILLING APPARATUS FITTED WITH HIGH-VACUUM PUMP

(*General Engineering Co. (Radcliffe), Ltd.*)

The aperture of the side branch at the point where it joins the down tube is so proportioned that the laws of gaseous diffusion operate at that point. Any air coming from the side tube will

diffuse into the stream of mercury vapour and be carried away by it, so that a steady reduction in the pressure in the side branch takes place. The vital factor in the successful operation of the pump lies in the correct dimensioning of the aperture of the side branch. Langmuir improved the apparatus by fitting a condenser

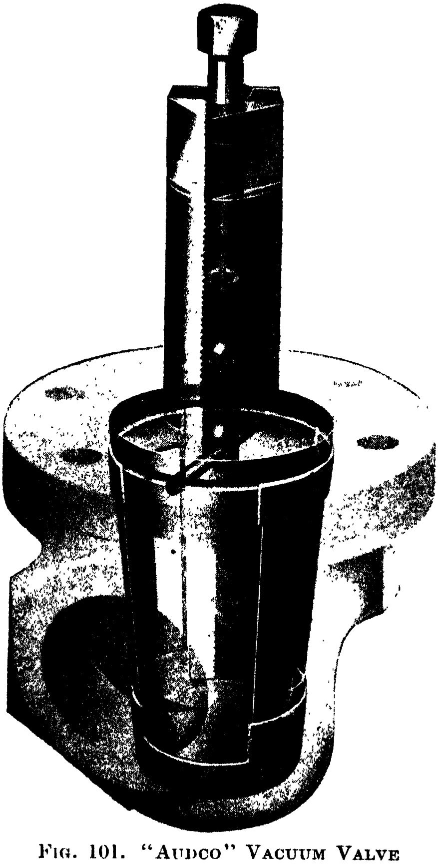


FIG. 101. "AUDCO" VACUUM VALVE
(*The Audley Engineering Co., Ltd.*)

around the diffusion aperture. This causes a rapid removal of mercury vapour by condensation, and assists the flow of air from the high-vacuum side branch to the backing pump.

Vacuum plant is extensively used in the food industry, and Fig. 100 shows a typical plant for the extraction of essences from fruits which are used in confectionery manufacture. One of the

advantages of using vacuum for this purpose is that the lower boiling temperature obtained preserves the flavours and reduces the time for evaporation.

The foregoing gives only a few examples of the many uses of vacuum plant. In construction, the manufacture of such plant should be left to specialists, since ordinary raw material is unsuitable, and specially rolled plates and special welding have to be employed. The vacuum lines require to be of special-quality tubing, and the valves are nearly always grease- or oil-sealed to prevent leakage of air into the system.

An illustration of a typical valve suitable for vacuum lines (the "Audco") is shown in Fig. 101.

There is a growing need, however, in industry to-day for still higher vacua, and for this purpose the Audley Engineering Co., Ltd., have designed a special disc valve which is shown in Fig. 102. This valve, which is tested optically for flatness, has been used extensively for research vacua and, in particular, for the famous experiment on "splitting the atom."

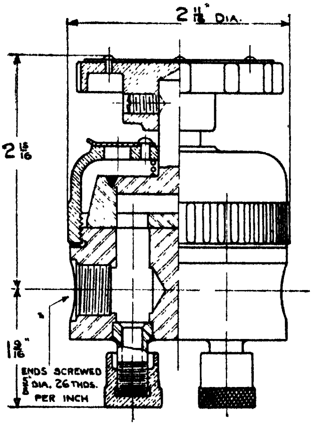


FIG. 102. HALF SECTION OF $\frac{3}{8}$ IN. "AUDCO" VALVE, TYPE "FB"

Showing internal construction and main dimensions.

This disc type of valve is used for rare vacua.

(The Audley Engineering Co., Ltd.)

Some idea of the size of vacuum plant will be obtained from Fig. 103, which shows a complete vacuum plant for the manufacture of high-tension paper dielectric cables.

The appended tables and formulae may prove useful.

Pump Size Required. Because of the effect of unknown conditions peculiar to any specific installation, it is impossible to determine exactly what size of pump would be required to obtain and maintain a required vacuum in a given system. The following formula, however, will serve to furnish an approximate figure for Kinney vacuum pumps when handling dry air—

Let V_1 = Pump displacement in ft.^{3} per min. required to deal with leakage into the system.

P = Absolute pressure inside the system in lb. per in.^{2}. (See Table X, page 147.)

T = Absolute temperature of gas coming to the pump (equal to temperature in $^\circ$ F. + 459·6).

W = Weight of gas leaking into system per min., in lb. (At 70° F., 1 ft.^{3} of free air weighs 0·0791 lb.)

R = Gas factor from Table IX, below.

Then, $$V_1 = RTW/P \quad . \quad . \quad . \quad . \quad . \quad (1)$$

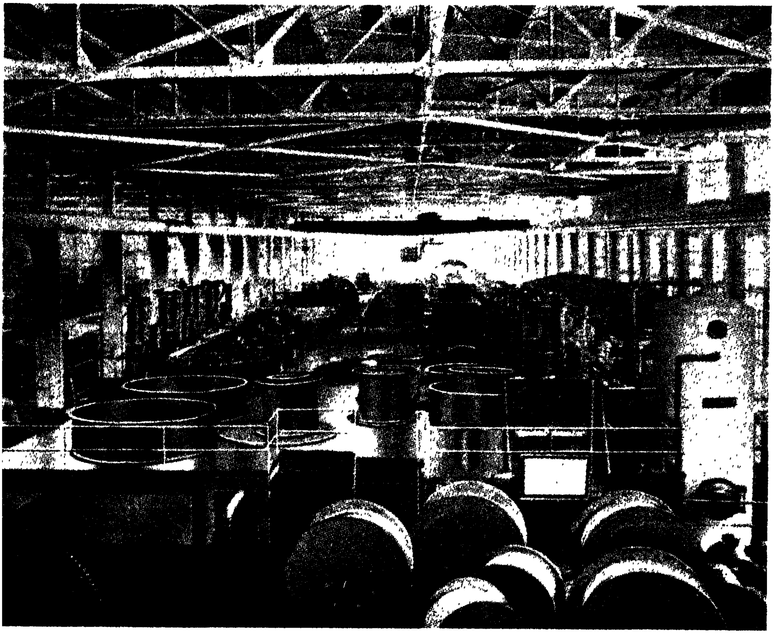


FIG. 103. COMPLETE HIGH-VACUUM PLANT FOR ELECTRIC CABLE INDUSTRY

(*General Engineering Co.* (*Radcliffe*), *Ltd.*)

The value of R in the above formula for various gases is as follows—

TABLE IX

Acetylene	0·458	Hydrogen	5·92
Air	0·412	Methane	0·743
Ammonia	0·70	Methyl chloride	0·236
Argon	0·299	Nitric oxide	0·397
Carbon dioxide	0·271	Nitrogen	0·424
Carbon monoxide	0·426	Nitrous oxide	0·2705
Ethylene	0·425	Oxygen	0·372
Helium	2·98	Sulphur dioxide	0·186
Hydrochloric acid	0·327		

In cases where gases are being withdrawn from a hot system, the introduction of a condenser or cooler between the system and the

pump will greatly increase its effective capacity. Where vapours are given off from material in the system, additional capacity must be furnished to deal with these vapours, unless they are condensed before coming to the pump.

Capacity Required to Produce a Given Vacuum. To calculate the pump capacity required to produce a given vacuum (assuming a perfectly tight and dry system)—

Let V_2 = Pump displacement in ft.^{3} per min. to produce given vacuum.

C = Capacity of system in ft.^{3}

F = Constant depending on vacuum required and obtained from Table X (below).

K = Factor depending on heat transfer conditions of the system and variable between 0·90 and 1·30.

M = Time allowable to produce given vacuum, in minutes.

Then, $$V_2 = CF/KM \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

TABLE X

CONSTANTS FOR VARIOUS VACUA

Vacuum (inches of mercury)	P	F	Power Constant	Vacuum (inches of mercury)	P	F	Power Constant
5	12·25	0·19	0·0200	28	0·98	2·74	0·0272
10	9·80	0·41	·0290	29	·490	3·43	·0218
15	7·35	0·70	·0364	29·5	·245	4·13	·0160
18	5·88	0·94	·0400	29·7	·147	4·65	·0120
21	4·31	1·21	·0415	29·8	·098	5·08	·0110
22	3·92	1·35	·0409	29·9	·049	5·77	·0100
24	2·94	1·63	·0382	29·95	·0245	6·47	·0100
25	2·45	1·81	·0361	29·97	·0147	6·98	·0100
26	1·96	2·05	·0336	29·98	·0098	7·40	·0100
27	1·47	2·32	·0308	29·99	·0049	8·10	·0100

The total capacity V required for any given dry system is given by

$$V = V_1 + V_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

To allow for leaks and other unknown contingencies, it is recommended that the capacity of the pump should be at least 20 per cent in excess of that indicated by the above formula.

EXAMPLE. To find the size of vacuum pump necessary to maintain a vacuum to within 0·1 in. of mercury absolute (i.e. to 29·9 in. when referred to a 30 in. barometer reading) on a given system with 0·1 lb. of free air leaking in per min., the system temperature being 70° F.

TABLE XI

Conversion Table of Vapour Pressure Relating to Temperature and Vacuum in Inches of Mercury

Temp. ° F.	Vacuum in In. of Mercury referred to a 30 in. Barometer Reading. (Mercury at 58·4° F.)	Absolute Pressure, Lb. per In.² Pv	Specific Volume, Ft.³ per Lb.	Latent Heat of Vaporization in B.Th.U.
32	29·8194	0·0887	3 296	1 073·0
34	29·8043	·0961	3 054	1 072·0
36	29·7881	·1041	2 832	1 070·9
38	29·7708	·1126	2 628	1 069·8
40	29·7522	·1217	2 441	1 068·8
42	29·7322	·1315	2 268	1 067·7
44	29·7109	·1420	2 109	1 066·6
46	29·6880	·1532	1 962	1 065·6
48	29·6636	·1652	1 827	1 064·5
50	29·6376	·1780	1 702	1 063·5
52	29·6097	·1918	1 587	1 062·4
54	29·5800	·2063	1 480	1 061·3
56	29·5483	·2219	1 382	1 060·3
58	29·5145	·2384	1 290	1 059·2
60	29·4786	·2561	1 206	1 058·1
62	29·4403	·2749	1 128	1 057·1
64	29·3995	·2949	1 055	1 056·0
66	29·3562	·3162	988	1 054·9
68	29·3102	·3388	926	1 053·9
70	29·2614	·3628	868	1 052·8
72	29·2094	·3883	814	1 051·7
74	29·1544	·4153	763	1 050·6
76	29·0960	·4440	717	1 049·6
78	29·0342	·4744	673	1 048·5
80	28·949	·507	632·9	1 047·4
82	28·899	·541	595·2	1 046·3
84	28·826	·577	560·0	1 045·3
86	28·749	·615	527·2	1 044·2
88	28·666	·655	496·6	1 043·1
90	28·579	·698	467·9	1 042·0
92	28·488	·743	441·2	1 041·0
94	28·391	·790	416·1	1 039·9
96	28·290	·840	392·7	1 038·8
98	28·182	·893	370·8	1 037·7
100	28·049	·949	350·3	1 036·6
102	27·949	1·008	331·1	1 035 5
104	27·824	1·069	313·0	1 034·4
106	27·692	1·134	296·1	1 033·3
108	27·552	1·202	280·3	1 032·2
110	27·406	1·274	265·4	1 031·1
112	27·252	1·350	251·3	1 030·0
114	27·091	1·429	238·2	1 028·9
116	26·921	1·512	225·8	1 027·8
118	26·743	1·600	214·2	1 026·7
120	26·556	1·692	203·2	1 025·6
122	26·360	1·788	192·9	1 024·5
124	26·153	1·889	183·2	1 023·4
126	25·939	1·995	174·1	1 022·2
128	25·714	2·105	165·5	1 021·1
130	25·477	2·221	157·3	1 020·0
132	25·230	2·343	149·7	1 018·9
134	24·971	2·470	142·4	1 017·8
135	24·84	2·536	138·9	1 017·2
140	24·12	2·887	123·0	1 014·4
145	23·32	3·280	109·2	1 011·5
150	22·43	3·716	97·1	1 008·7
155	21·45	4·201	86·5	1 005·8
160	20·35	4·739	77·3	1 002·9
170	17·73	5·992	62·0	995·8
180	14·64	7·51	50·1	989·9
190	10·91	9·34	40·9	983·9
200	6·48	11·52	33·6	977·8
212	0	14·7	26·79	970·4

$$\begin{aligned} R \text{ (for air)} &= 0{\cdot}412 \text{ (Table IX)} \\ P &= 0{\cdot}049 \text{ (Table X)} \\ T &= 459{\cdot}6 + 70 = 529{\cdot}6 \\ W &= 0{\cdot}1 \end{aligned}$$

Then from formula (1), $V_1 = \dfrac{0{\cdot}412 \times 529{\cdot}6 \times 0{\cdot}1}{0{\cdot}049} = 445.$ ft.^{3} per min.

Now let it be assumed that the cubic contents of the gas space in the above system amount to 200 ft.^{3}, and that it is desired to produce the given vacuum in the system in 20 min.

Then from formula (2), $V_2 = \dfrac{200 \times 5{\cdot}77}{0{\cdot}9 \times 20} = 65$ ft.^{3} per min.

Total pump displacement required, from formula (3)

$$= 445 + 65 = 510 \text{ ft.}^3 \text{ per min.}$$

To allow for leaks, etc. (see page 147), this figure should be increased by 20 per cent, making a total pump displacement of 612 ft.^{3} per min.

TABLE XII

INFORMATION CONCERNING VAPOUR TENSION OF ICE

Temperature ° F.	Absolute Vapour Pressure, mm. of Mercury	Temperature ° F.	Absolute Vapour Pressure, mm. of Mercury
32	4·58	4	1·18
30	4·14	2	1·07
28	3·89	0	·96
26	3·46	− 2	·89
24	3·14	− 4	·78
22	2·86	− 6	·697
20	2·62	− 8	·626
18	2·38	− 10	·562
16	2·15	− 12	·503
14	1·95	− 14	·45
12	1·77	− 16	·402
10	1·60	− 18	·36
8	1·44	− 20	321
6	1·31	− 40	·0966

These figures should prove valuable to engineers concerned with vacuum plant. They have been well proven in practice, and are reproduced by kind permission of the General Engineering Co. (Radcliffe), Ltd.

CHAPTER IV

ELECTRICAL EQUIPMENT

THE care and maintenance of the electrical equipment is perhaps the most important factor in the service department of a works, and some knowledge of electrical theory is essential to the present-day Works Engineer.

SUPPLY AND GENERATION

Types of Supply. While many older factories use a direct current (d.c.) supply, most modern factories are equipped for alternating current (a.c.), since the latter has the following advantages—

(1) Where the power supply is obtained from outside, it is nearly always a.c., usually at a high voltage. This can be readily changed to a low alternating voltage by means of transformers; but to obtain low voltage d.c., converting apparatus is required in addition.

(2) Should voltages be required other than the supply voltage, they can easily be obtained by means of transformers situated in the locality of the process requiring the exceptional pressure.

(3) The usual system of distribution is *three-phase*, for which the amount of cable needed for transmitting a given power is less than with d.c.

(4) In general, the cost of a.c. motors and starters is considerably less than that of d.c. motors, and there are no, or few, moving contacts.

(5) There is very little danger of electrolysis occurring in the cables.

The only advantages of d.c. supply are—

(1) Where variable-speed or high-speed motors are required, or motors requiring a large starting torque, d.c. motors are preferable. Variable- or high-speed motors are generally few, however, therefore the balance is usually in favour of a.c.

(2) D.c. supply is less dangerous to life than a.c. In a properly organized supply, however, such a consideration should not carry any weight, since modern electrical equipment, properly installed, provides ample safeguards.

(3) Where there is any considerable employment of accumulators or where arc lamps are used, a d.c. supply is necessary. D.c. is also preferable to a.c. for welding, as there is less danger from shock.

(4) It is easier to run generators in parallel when d.c. is used.

D.C. Supply. This is generally at 460 volts, 3-wire, with the mid-wire earthed, allowing the use of 460 volts for medium-size and large motors, and 230 volts for small motors and lighting. In

small factories a supply at 200 to 250 volts may be used, preferably with the positive earthed to prevent electrolysis.

The 3-wire system enables power to be distributed at twice the voltage allowed for lighting, and consequently leads to a big saving in copper. A third wire is connected between the generators, as shown in Fig. 104. This is the neutral conductor, and the loads, whether machines or lamps, are arranged as far as possible to be "balanced," i.e. the loads between the neutral wire and the two outer wires (positive and negative) should be as nearly equal as possible. If the loads are *exactly* balanced, the neutral will not be required to carry any current. The cross-sectional area of the

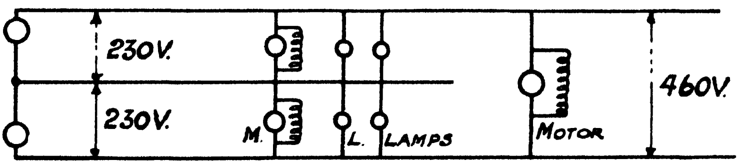


FIG. 104. THREE-WIRE SYSTEM
D.c. diagram of wiring for motors and lamps

neutral wire is often made about half that of the outer wires, and a corresponding saving in copper is thus effected. If the system is well balanced, the neutral wire area may be as small as one-third of the outer. This system is almost universally used in d.c. distribution. Should any *single* heavy load have to be included, such as a powerful motor, the existing balance can be preserved by connecting the heavy load alone across the two outer wires, so that the balance is unaffected.

The size of the conductor cables, whether for d.c. or a.c., depends on the current flowing, and in order to keep down the cost of the copper required, the voltage must be kept high for distribution. The voltage is, however, subject to the regulations of the Electricity Commissioners, and, though it may be (as is usual) supplied at pressures of 460–500 volts for industrial use, 250 volts is the maximum allowed in buildings for lighting purposes; and when allowance is made for the percentage of variation permitted, this figure is nearer 230 volts.

A.C. Supply. Whilst three-phase a.c. supply is becoming universally adopted, there are perhaps a few factories which still have a single- or two-phase supply; and whilst space will not permit of a full description of each method, a brief outline of the different systems may not be out of place. These systems are shown diagrammatically in Fig. 105. If the supply is two-phase, either a 4-wire or a 3-wire system may be used. The latter shows a saving in copper over the 4-wire system, as is obtained by 3-wire d.c. distribution compared with the d.c. 4-wire system.

SINGLE-PHASE. For lighting this is ideal (providing the periodicity is high enough to eliminate the "flicker" of the alternations of the current), whereas when three-phase current is used it is sometimes difficult to arrange the lighting load so that all three phases are equally balanced. For motors, however, the starting torque is very low and there is the possibility of burning out the windings due to machines not starting when switched on, unless more expensive types of motors, such as repulsion motors, are used.

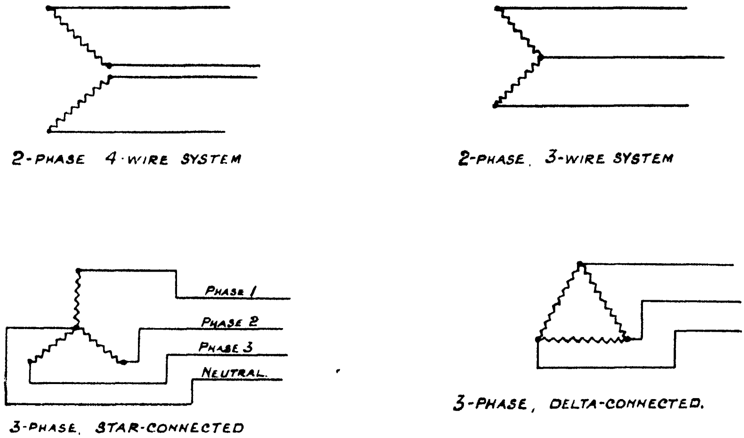


FIG. 105. DIAGRAMS OF A.C. WIRING SYSTEMS

TWO-PHASE. There are two systems of two-phase supply, *4-wire* and *3-wire*. In the 4-wire system, two pairs of leads are led to the motor and each lead has to be large enough to carry the single-phase current. Referring to Fig. 105, it will be noted that the two inner wires may be connected together, making one common line between the two phases; this is known as the 3-wire system, and the common wire has to be of larger diameter. Actually, this wire is only required to be 1·41 (or $\sqrt{2}$) times the diameter of the other two phase wires, for a balanced load.

THREE-PHASE. There are two common methods of connecting the respective phases in a three-phase supply, and they are known as *star* connection and *delta* connection. They are shown diagrammatically in Fig. 105, using the conventional method of representation by which the phase angle is 120° between any two phases. In delta connection the voltages between pairs of lines are equal to the voltage in the phase winding between them, but this is not true of the line currents. For a balanced delta-connected system, the line currents are 1·732 (or $\sqrt{3}$) times the phase winding currents, since each line wire must carry the vectorial sum of two winding currents.

Conversely, for star connections, the voltage between any two

line wires will be $\sqrt{3}$ times the phase voltage but the current in the lines will be equal to the phase current. When the system is balanced, the vector sum of the line currents is zero, and hence, the neutral wire carries no current. For a perfectly balanced star-connected system, the neutral wire is therefore unnecessary; where perfect balance cannot be attained, the neutral wire is included and for this purpose from one-half the diameter up to the same diameter of the phase wires, is used.

Power House Location Relative to Distribution Network. The location of the power house is a primary consideration in electrical layout. A geographical centre may not be the best distribution centre, and the plant layout of the factory should be carefully studied before deciding on the location, or even the extension, of an existing power house. In a small factory the distribution network may be a cable system controlled direct from oil switches in the power house, supplying distribution boxes in the locality where the service is required. For medium-sized works, a number of low-tension sub-stations are advisable in various parts of the works, and from these the network cables to the distribution boxes may be extended. The advantage of this method of distribution is that the cables run from power house to sub-station, are large and relatively few, and thus much small and untidy wiring is eliminated. The switchgear in the sub-station should be clearly marked with its covering circuit-breaker number, and the distribution box circuits should also be identified by means of a card in a suitable holder fixed to the distribution box door. Clear identification of all circuits is an invaluable feature of distribution, and no effort should be spared to make circuit location as easy as possible. Detailed information regarding distribution will be given later, but it is considered advisable to follow the system from power house to distribution boxes at this juncture, in order to show how the location of the power house is affected by the distribution network.

Whilst it is desirable to have the power house in the best possible position for distribution, there are other questions that have a bearing on its location. If all or part of the power is generated, it is essential that the power house should be adjacent to the boiler house, to reduce heat transmission losses to a minimum. Cooling water is another item, but as it is usual for the boiler house to be situated near a canal or river wherever possible, this falls in with the general arrangement.

The effect of vibration may sometimes be serious, especially if the prime movers are internal combustion engines. Foundations must be made sufficiently massive to minimize this tendency. Cases are on record where vibrations from internal combustion engines have caused such serious settlements in chimneys or in heavy portions of buildings, that the latter have become unsafe and have had to be rebuilt.

The power house should be of sufficient height to give adequate ventilation, and if possible should have a basement for steam mains, cable racks, etc., with either good natural or forced ventilation. High-tension and low-tension panels and transformers should be arranged so that extensions, to accomodate extra equipment, can be built on. The walls and floors should be suitably tiled, and steelwork should be painted a light colour so that the place can be kept spotlessly clean. This is money well spent, as not only will the equipment itself then be kept clean, but it will be looked after better generally; a clean building gives the attendant just the necessary encouragement to keep his plant in the same condition.

Transformer Location. In many cases these are placed in some inaccessible corner or basement, and are then considered to be "nicely out of the way." This is not the attitude to adopt towards what may be considered the heart of the power supply, if current is taken from a local supply authority. Transformers should be placed in well-ventilated, well-lighted, and accessible positions, or outside the building altogether, with means for removing them complete, or for extracting faulty cores for replacement.

It is a good plan to have all transformers of the same type and capacity, connecting them in parallel. This method enables transformers to be introduced, or taken out of service, as desired—dependent on load conditions. Faulty transformers may be removed completely, the load being temporarily distributed over the remaining transformers, until the spare core or transformer is installed. A complete spare core, or better still, a complete spare transformer, is an invaluable asset in case of failure.

Where power is taken from bulk supply, the oil switches controlling the transformers should be located near an outside wall, at the point where the cable enters.

To bring the supply from the switchgear to the transformers, floor ducts are more favourably regarded than overhead cable racks, if a basement is not provided. Such ducts may be covered by any method suitable for the particular case, but in all circumstances they should be easy of access, for fault location or cable alteration. A point regarding these duct covers which may be overlooked, is that they may be called upon to carry the weight of any transformer or plant in the power house, and they should be constructed accordingly.

Cabling. It is desirable at this point to deal with the selection of suitable cables for motor operation. The type of cable depends, of course, on the voltage of the incoming supply. Sometimes single-core cables are used in preference to multicore cables, especially when the cross-sectional area of the conductors required is very large, the former being much more flexible than the latter. Entry into transformers and switchgear is thus facilitated, and the need for large trifurcating boxes eliminated.

From the distribution board to the motor switchgear on long runs, lead-covered vulcanized indiarubber cables are usually employed, as in most cases they are found to be more flexible, and more economical in labour cost. From the motor switch to the starter and motor, plain brazed lug-grip tube and fittings, with flexible tube connections to the starter and motor, should be used. The flexible tube should terminate at the girders or trusses supporting the motor channels. Wiped joints should be used in connecting the flexible tubing, in order to preserve the continuity of the earth line.

The size of cables can be determined from the following formulae—

D.c. motors

$$\text{Current in line (amperes)} = \frac{\text{H.P.} \times 746 \times 100}{\text{Volts} \times \text{Efficiency } \%}$$

Single-phase a.c. motors

$$\text{Current in line (amperes} = \frac{\text{H.P.} \times 746 \times 100}{\text{Volts} \times \text{Efficiency } \% \times \text{Power Factor}}$$

Two-phase a.c. motors (4-wire connection)

Current in line (amperes)

$$= \frac{\text{H.P.} \times 746 \times 100}{2 \times \text{Voltage of one phase} \times \text{Efficiency } \% \times \text{Power Factor}}$$

Two-phase a.c. Motors (3-wire connection)

Current in two outer lines as above (for 4-wire connection).
Current in neutral: 1·414 × current for 4-wire connection.

Three-phase a.c. motors

Current in line (amperes)

$$= \frac{\text{H.P.} \times 746 \times 100}{(\sqrt{3}) \times \text{Volts} \times \text{Efficiency } \% \times \text{Power Factor}}$$

Reference to manufacturers' lists giving the current-carrying capacities of cables will indicate the size required for the above currents.

SWITCHGEAR

For power station and sub-station use there are many types of switchgear available. Space will not permit the description of these varieties, but modern industrial practice favours the metal-clad types, in which there are no exposed conductors. The stone or concrete cubicle type is also popular for high voltages and has many points in its favour.

Distribution boxes and motor switchgear and starters should invariably be metal-clad, to comply with Home Office regulations, and the covers should be interlocked with the switch handles so

as to make the apparatus "dead" before the cover is opened for purposes of inspection and maintenance.

In making connection of load to supply, it is essential that the operation shall be performed quickly and positively. A switch which, for any reason, makes contact slowly is liable to have the face of the contacts burned by arcing; the same applies to breaking contact. The disconnection of a load should be done as rapidly as possible, to reduce the time of the arc-dwell upon the contacts. The suppression of the arc is a matter of primary importance, and it is essential that arc shields should be maintained in good order and position. Switch manufacturers sometimes err in this respect, and occasions may arise when the maintenance engineer has to devise a shield to prevent arcing to the frame, or to another phase. Where this fault occurs there is usually overloading and as a temporary measure the switch interior should be lined with fireproof insulation. Oil switches may arc to earth as the result of negligence. Contacts may come loose and swing about, thereby reducing momentarily the arcing space; or the oil level may become low, whereby ionization is rendered easier than would be the case were the arc quenched in oil.

For general three-phase power circuits it is usual to employ oil-immersed switches having two overloads and one no-volt release. It may be considered desirable in some cases to have three overloads, particularly where the load is unbalanced, individual trips being set to suit individual phase loads. It is usual, in this type of switchgear, to make the operating handle independent of the switch-tripping mechanism; this prevents the switch from being held in on short-circuit or overload. Modifications of switchgear design should not interfere with this principle.

Magnetic tripping devices are usually operated by means of moving iron cores which are drawn into the magnetic field set up by the line currents flowing through the overload coils, the cores being suitably arranged so as to operate the trip mechanism. The core should always be in a position well below the magnetic centre, otherwise excess current will not operate the trip. Should a coil former be damaged and a new one required, care must be taken to split the metal former down one side, from end to end; this prevents the former acting as a closed single-turn secondary and consequently becoming heated.

Circuit-breakers. These are essentially automatic switches fulfilling the combined duties of switches and fuses.

Whilst air circuit-breakers are usually equipped with some device for controlling or quenching any arcs formed, liquid-break circuit-breakers have their contacts immersed in liquid, which is, usually, insulating oil (Fig. 106).

Arc control devices aim either at cooling the products of the arc by oil immersion, or at using the energy liberated by the arc for removing the arc from between the switch contacts.

In the former the hot gases generated by the arc are cooled by the oil, and since air is excluded, oxidization is minimized. In the latter the arc may be regarded as a conductor carrying current. It

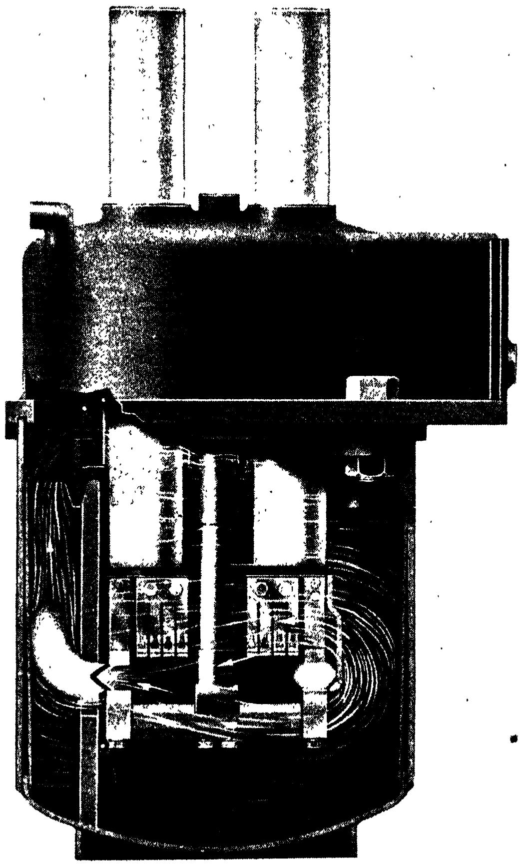


FIG. 106. CONSTRUCTION OF CROSS-JET BOX FOR LIQUID-BREAK CIRCUIT BREAKER
(*I.Mech.E.*)

is well known that a current-carrying conductor will move out of a magnetic field, and in the case of a circuit-breaker this field is produced by making the line currents circulate through a coil which has its iron core extremities so situated that the flux developed between them is diagonally opposite to the arc. The centre of the

arc is consequently pushed away from the contacts until it is finally broken, the effect being similar to that produced by the rupturing of the elastic in a catapult.

When a power-operating device is used for a circuit-breaker, it may be either a solenoid with closing linkage, or a motor-operated mechanism. The latter is suitable when no direct current is available, as a small transformer can be connected to supply an a.c. series commutator motor. Motor-operated devices often depend on the centrifugal force from two balls, arranged like those of a steam-engine governor, to supply the pull on the closing linkage.

If the circuit-breaker is of the liquid-break type, care should be taken to see that the gasket between the oil pot and the top chamber is not too *thick*, otherwise there may be a tendency for it to be blown out when arcing occurs. If the wall of the oil pot is loosely spigoted into the cover and a thin gasket inserted between the metal surfaces, the best joint will be obtained. A "sticker" material such as shellac or synthetic resin may be brushed over the gasket when in position.

If switching operations are frequent, as when large motors have to be started or stopped on load, something better than the plain arcing finger will be needed. The amount of metal in the contacts must be so great that there will be little tendency for them to "freeze" together on contact when heavy currents are flowing; there must be a "wiping" action between the arcing fingers and the arcing block attached to the cross bar.

Rupturing Capacity of Switchgear. Where power is taken from the supply authority in bulk, care must be taken to see that all circuit-breakers are of sufficient capacity to rupture efficiently a short-circuit current, thus safeguarding the transformers from what would otherwise result in very serious breakdown.

If the circuit-breaker is not designed to rupture the enormous currents which may circulate in the system on short-circuits, it is possible that the switch may be blown to pieces by the gases which are formed when the contacts open. The relatively high value of short-circuit currents will be noted after consideration of the formula for calculating such values.

The short-circuit current is limited almost entirely by the impedance of the transformer, and the capacity of the incoming supply. If this impedance is not known it may be assumed, for most ordinary power transformers, to be approximately 6 per cent, based on the normal rating of the transformer. The maker will supply details of impedance on request if this is desired more accurately. If the impedance is x per cent then—

$$\text{Short-circuit kVA.} = (100/x) \times \text{normal kVA.}$$

and in the case of a 1 000 kVA. transformer at 6 per cent impedance the short-circuit kVA. would equal $(100/6) \times 1\,000 = 16\,000$ kVA.

approximately, providing the incoming supply is of infinite capacity. The protecting circuit-breaker must be of sufficient capacity to break this current efficiently.

Now that supplies are being "ringed up" on the grid system, the sizes of switchgear and transformers on the supply authorities' system are being greatly increased in a number of cases, and it is advisable for the consumer to take up this matter with the supply company from time to time to ensure that the rupturing capacity of their switchgear is sufficient to take a short-circuit on their side of the supply. This affects both low- and high-tension switchgear.

INSTRUMENTS

The following are the chief types of electrical instruments.

Moving Iron. In this type the moving element consists of an iron vane which moves in a magnetic field produced by a fixed coil. The strength of the magnetic field set up by this coil varies according to the value of the quantity to be measured. Instruments of this type are suitable for a.c. and d.c. use, though when used for the latter case they are not accurate, unless specially designed. They have the advantage of being more robust than the moving-coil type, and cheaper.

It is most important to screen these instruments from external magnetic fields, by providing an iron case.

Moving Coil. In this class the moving element is a coil, the current in which varies in proportion to the quantity to be measured, and which moves in a magnetic field produced by a fixed permanent magnet. Movement is due to the torque produced by the interaction of the two fields. Since the permanent magnet field is constant, the deflection varies directly with the current, and the scale therefore carries *equal* divisions. This type cannot be used for a.c., since a reversal of current will reverse the direction of rotation of the coil.

Hot-wire. Instruments of this type depend on the expansion of a length of wire due to heat caused by the passage of the current. They are not generally used for industrial work. They find their most useful application in the case of high frequencies, for which instruments with coil windings are not suitable. These instruments follow a "square" law, and the scale therefore carries unequal divisions. They can be used equally well for d.c. Their chief disadvantage is the large amount of power they consume.

Electrostatic. This type depends for its action on the mutual attraction of oppositely charged bodies. This attraction is directly proportional to the *square* of the potential difference between the bodies and to the area exposed; it is also *inversely* proportional to the distance separating the two surfaces. Such instruments are, therefore, only suitable for voltmeters, and consist of sets of fixed and moving vanes, similar to a condenser, which are connected to the voltage to be measured. They are suitable for measuring high voltages and consume very little energy.

Wattmeters and Watt-hour Meters. These fall into two classes—

(*a*) *Dynamometer Instruments*, in which there are two sets of coils, one fixed coil carrying the current, and the other carrying a current which varies with the voltage; the latter is pivoted so as to be free to rotate in the field produced by the former coil.

(*b*) *Induction Instruments*, which can only be used for a.c. As in dynamometer instruments, these also contain two sets of coils, the action depending on the eddy currents produced by the two sets on a disc which is free to rotate, after the style of a squirrel-cage induction motor. A permanent magnet fixed near the disc provides the necessary damping.

The reading of both types of instrument is dependent on the power factor, and actually represents the energy component of the current flowing. For this reason these instruments are known as *energy meters.*

Power Factor (P.F.) Meters. These meters give an indication of the percentage of the total input kVA. which is being converted into useful energy. For example, a meter indicating 0·8 p.f. lagging, shows that, due to the inductive reactance of the motors, etc., only 80 per cent of the input kVA. is being converted into useful energy; i.e. for 100 kVA. input, 80 kVA. is doing useful work and 20 kVA. is circulating in mains and switchgear and is virtually idle current.

The actual operation of these meters would take too much space to describe here.

Frequency Meters. These indicate the rate of reversal or alternation of a.c. potentials. Two only of the principal types will be very briefly explained.

(*a*) *Vibrating Reed Type.* These meters consist of a number of steel reeds or springs which are subject to the influence of a magnetic field generated by a coil connected to the supply. A number of reeds, usually covering a range of 5 per cent from normal, are fitted, and the reed which has a natural frequency corresponding to the supply frequency vibrates in resonance, and a scale arranged near the vibrating reed indicates the frequency of the supply.

(*b*) *Induction Type.* This type of meter depends for its operation on the eddies produced in a disc which is free to rotate. These eddies are produced by two coils, one fed from the supply through an inductance, the other through a resistance, each coil opposing the rotation produced by the other. The higher the frequency, the greater becomes the impedance offered to current passing through the inductive coil, and since the frequency can have little effect on the resistance coil, the torque produced by the latter is predominant. The disc therefore endeavours to rotate in the direction favoured by the resistance coil, and movement of the pointer over the scale indicates a raising or lowering of frequency dependent on the ratio of torque produced by the two coils.

POWER SUPPLY PLANT

Transformers. The essential feature of a transformer is the use of a magnetic circuit to link together two coils or windings, known as the *primary* and *secondary*. Thus, if an alternating e.m.f. is applied to a coil which embraces an iron core, a magnetic flux alternating at the same frequency will result, within and surrounding the iron core. If a second coil is placed on the core, the varying flux will induce within it an e.m.f., which will be of opposite polarity to the applied e.m.f., that is, the angle between two vectors representing them will be 180° (see Fig. 107).

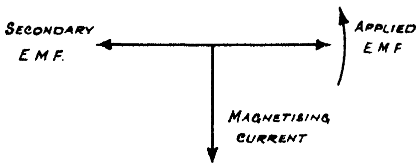


FIG. 107. VECTORIAL DIAGRAM OF TRANSFORMER E.M.F.

The voltage ratio between the two windings will be equal to the ratio of the number of primary turns to the number of secondary turns.

The arrangement described represents in its most elementary form a single-phase transformer. For power purposes the single-phase supply suffers serious disadvantages, since phase-splitting devices have to be included in the starting equipment of motors in order to give rise to a rotating field which will produce a torque.

Two-phase Transformers. In a two-phase supply the phase angle ween voltage vectors is 90°, and since the flux due to these e.m.f.'s is also displaced 90°, torque results without introducing auxiliary apparatus into motor circuits. The two phases may be electrically isolated by operating the system on a 4-wire principle, or they may be connected as shown in Fig. 108, which represents the 3-wire system.

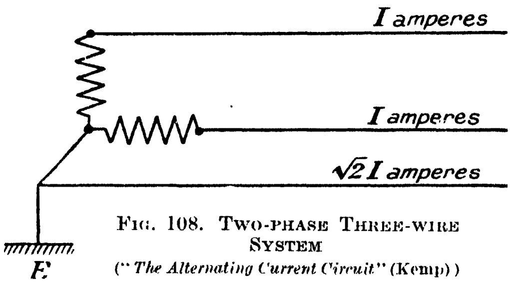


FIG. 108. TWO-PHASE THREE-WIRE SYSTEM

("*The Alternating Current Circuit*" (Kemp))

In this arrangement, supposing the voltages and currents in the two phases to be similar, the value of the voltage between the two outer wires will be equal to $\sqrt{2} \times$ phase voltage, and the current in the common wire will be $\sqrt{2} \times$ phase current. It is the general practice to earth the common point of the two phases.

Three-phase Transformers. This type is ideal where both power and lighting supply are required. Three terminals project from the iron case on the input—generally the high-tension—side of the

transformer, to which are connected the three cores of the incoming supply cable. On the opposite—usually the low-tension—side of the transformer, project four terminals, star-connected, three of which correspond to the supply phases, the other being the common point of the three-phase windings, and referred to as the *neutral.*

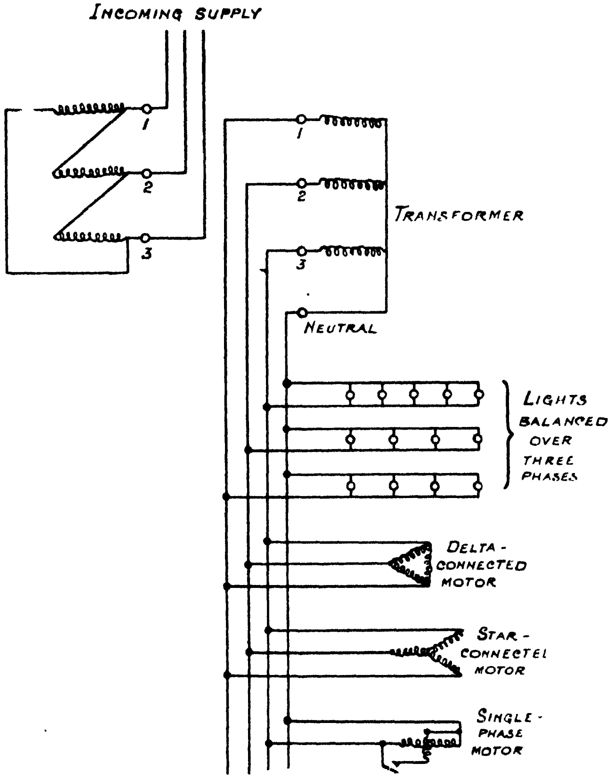


FIG. 109. THREE-PHASE TRANSFORMER CONNECTION

This terminal is commonly earthed, which has the effect of reducing fault pressures to the voltage of the phase-to-neutral, instead of the voltage of the phase-to-phase, pressure. The general arrangement of this type is shown in Fig. 109.

TRANSFORMER TYPES

Indoor Type. These are generally used for ordinary factory supply work. The high-tension side is usually fitted with tapping terminals to adjust the output voltage within limits of approximately 5 per cent. This type of transformer consists of a steel case,

usually welded, with tubes projecting from the tank to act as cooling agents. Channels on the bottom of the case are fitted with rollers to facilitate moving; a thermometer pocket and oil level indicators are fitted, and a plate indicating the rating and connection of the windings is usually fixed in a conspicuous place.

Outdoor Type. These are generally similar in construction to indoor types, except that the case and all fittings are made to withstand weather. The lid usually overlaps the top of the case, forming an effective seal against rain and mist, and is slightly domed to prevent rain accumulation. Outdoor transformers, usually being of a larger size, are generally fitted with an oil conservator, which permits expansion of oil without allowing the products of atmospheric contamination to enter the main transformer tank. The conservator may be fitted with a "breathing" device which can be arranged to dry the air sucked in by contracting oil. Outdoor transformers are usually arranged within an area fenced with unclimbable fencing to which are attached "DANGER" notices indicating the high-tension pressure.

Pole Mounting Type. As indicated by the name, these transformers are employed on the distribution network, usually for tapping high-tension mains for supplying remote districts or loads which adjoin the route of the main network. They are essentially an outdoor type, and in some cases are fitted with "tails" which are connected to the windings of the transformers for connection to the mains and load.

Auto-transformers. In these transformers the whole of the winding is connected across the supply and a tapping point or points are provided, from which a load may be operated at some percentage of the supply main voltage such as for starting motors at, say, 60 per cent mains pressure, etc.

This type may also be arranged to "step up" or increase the mains voltage, by connecting the mains to a tapping point at some percentage of the winding and using the extremity of the winding as a higher-pressure supply.

General Notes. Transformers are made for an infinite variety of purposes too numerous to mention here, but special precautions are taken when designing transformers for mining purposes or for duties where they will be subject to acid atmosphere. In all such special cases the advice of the manufacturer should be sought. Transformers can be arranged to step up the voltage or to step it down, i.e. to raise the voltage for transmission over long lines or to step down at the receiving end of long lines.

Special transformers for insulation testing or high pressure may be arranged to operate from very low-voltage supplies, and can also be mechanically and electrically modified to suit a large variety of conditions.

Conversion of Three-phase Current to Two-phase: Scott-Connection Transformer. This type of transformer is employed where it is

desired to operate two-phase plant from a three-phase supply, or vice versa. The arrangement of the coils and resultant voltages are shown in Fig. 110.

If two-phase output is required, terminals ABC are connected to a three-phase supply and a two-phase supply may be obtained from terminals $L_1 L_c L_2$. Connecting terminals $L_1 L_c L_2$ to a two-phase supply will result in three-phase output at ABC.

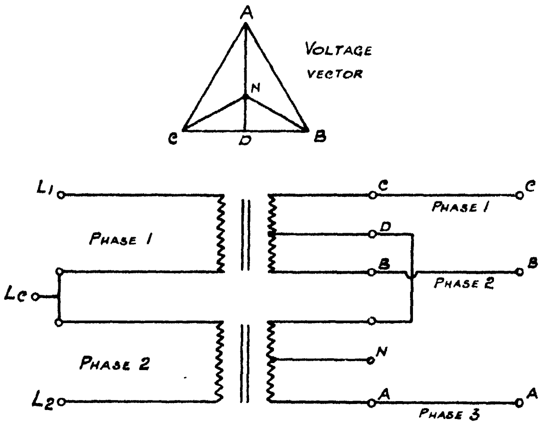


FIG. 110. SCOTT-CONNECTED TRANSFORMER

Parallel Connection of Transformers. It is important to note that two transformers can only be run in parallel if the primary and secondary voltage vectors are in the same relationship in both transformers, e.g. a star-star-connected transformer cannot be connected in parallel with a star-delta-connected transformer. The vector diagram or winding arrangement is usually shown on the rating plate of a transformer. Fig. 111 shows the phase angle between primary and secondary for the different types of three-phase connection. Only those transformers which have similar phase displacement and sign can be operated in parallel.

Phasing-out of Transformers for Parallel Operation. Before connecting a new transformer to supply, it is essential that its polarity and phase rotation should be of the same order as the other member of the group. This means that the voltage in each phase must be at every instant vectorially equal to the voltage of the bus-bars to which it is to be connected.

The simplest form of test for this purpose is to connect a voltmeter between the terminal of the transformer and the bus-bar on each phase. If no deflection results, then it can be assumed that there is no potential difference, and the connections can be made. If a deflection of the pointer results, however, the phases are wrong and should be changed over until the correct combination is obtained.

Transformer Oils. Care must be taken to see that the oil in transformers is kept free from foreign matter. It should be periodically cleaned by means of a centrifugal separator, such as the De Laval, to keep down the sludge to a minimum.

Before "topping up" or refilling a transformer with oil, it would be wise to refer to British Standard Specification No. 148, which indicates the quality and dielectric strength of the oil. On no account should ordinary oils, such as lubricating oil, be used for this purpose.

Variations in the load on the transformer cause air to be drawn into, or driven out of, the transformer tank. In the presence of this

PRIMARY

SECONDARY								
	0	$\pm 60^\circ$	$+30^\circ$	-30°	$+30^\circ$	-30°	$+30^\circ$	-30°
	$\pm 60^\circ$	0	-30°	$+30^\circ$	-30°	$+30^\circ$	-30°	$+30^\circ$
	-30°	$+30^\circ$	0	$\pm 60^\circ$	0	$\pm 60^\circ$	0	$\pm 60^\circ$
	$+30^\circ$	-30°	$\pm 60^\circ$	0	$\pm 60^\circ$	0	$\pm 60^\circ$	0
	-30°	$+30^\circ$	0	$\pm 60^\circ$	0	$\pm 60^\circ$	0	$\pm 60^\circ$
	$+30^\circ$	-30°	$\pm 60^\circ$	0	$\pm 60^\circ$	0	$\pm 60^\circ$	0
	-30°	$+30^\circ$	0	$\pm 60^\circ$	0	$\pm 60^\circ$	0	$\pm 60^\circ$
	$+30^\circ$	-30°	$\pm 60^\circ$	0	$\pm 60^\circ$	0	$\pm 60^\circ$	0

FIG. 111. PHASING OF TRANSFORMERS

air, any heated transformer oil will tend to form sludge; moreover, the air always contains a certain amount of moisture, which gets into the tank and condenses there when the transformer cools. For preventing the formation of sludge and the condensation of moisture, small expansion tanks, called *conservators*, are sometimes fixed above the tank proper, so that the latter is not affected. Every year transformers should be overhauled and examined for deterioration of insulation, slack core-clamping bolts, and moisture and sludge in the oil. If the latter is excessive the oil should be renewed. A sample of oil should be submitted for chemical analysis to ascertain the percentage of acidity.

POWER FACTOR CORRECTION

Since supply authorities must provide cable of sufficient size to carry the current irrespective of the power, it follows that their charges are usually based, not only on the power, but also on the power factor. The most usual bases for charges are either (*a*) a fixed charge per kVA. of maximum demand plus a charge per kWh., or (*b*) a charge per kWh. with a penalty if the power factor falls below a certain value (say 0·8). It is, therefore, most important that steps should be taken to avoid a low power factor on the factory system. Unfortunately, the cheapest form of a.c. motor, namely, the induction motor, has a lagging power factor which varies from about 0·9 at full load to as low as about 0·25 at no load. Since it is usually impossible to arrange for motors to run continuously at full load, some form of compensation is necessary. This can be effected in three ways: (1) by using for one or more of the largest motors a type which works at a leading power factor; (2) by installing static condensers, either small ones individually in association with each motor, or a large one in the works sub-station or power house; or (3) if part of the load is supplied from an alternator in the works driven from a back-pressure engine or turbine, by arranging for this to supply the low power factor load, so that the load obtained from the supply authority is at a high power factor. These methods will now be described more fully.

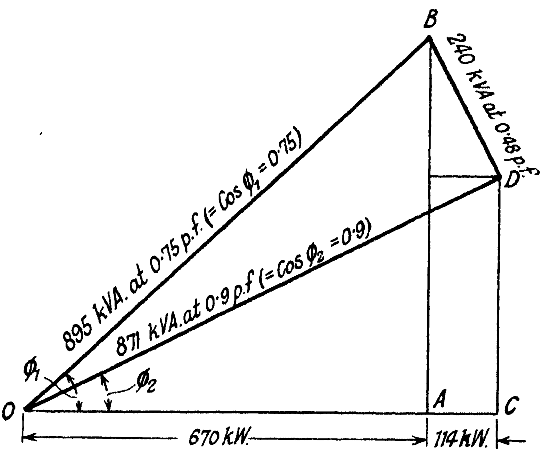


FIG. 112. POWER FACTOR DIAGRAM

(1) **Power Factor Correction Motors.** SYNCHRONOUS MOTORS. It is a property of the synchronous motor that its power factor can be varied by varying the excitation of the field (usually the stator), and that over-excitation will cause the power factor to lead, and vice versa. Where a steady load requiring a high power (such as an air compressor) is involved, the installation of a synchronous motor is worthy of consideration. Small motors are never economical, due to the cost of the d.c. excitation and more expensive construction.

The speed of a synchronous motor is fixed in relation to the supply frequency and is dependent on the number of poles. The relation

between speed and frequency is therefore the same as an alternator; and in point of fact the construction of a synchronous motor is the same as that of an alternator. Therefore, a definite speed has to be decided on before the motor is ordered from the maker. As with the alternator, also, a d.c. source for field excitation is necessary.

A synchronous motor must be run up to speed before it can take the load. Where, therefore, it is impossible to run the machine up with the load off, the pure synchronous motor cannot be used.

The calculation of the amount by which the power factor of the synchronous motor must lead in order to effect the required correction is best shown by a typical example, worked graphically.

Assume that the factory load (excluding the synchronous motor) is 670 kW. at 0·75 p.f. on a 400-volt three-phase supply, and that the horse-power of the synchronous motor is to be 140, and that it is required to correct the power factor to 0·9.

$$\text{kVA. input to factory} = \text{kW./p.f.} = 670/0{\cdot}75 = 895.$$

Referring to Fig. 112, construct the angle AOB (ϕ_1) such that its cosine is equal to the power factor, namely, 0·75. Now mark off $OA = 670$ and $OB = 895$ to some suitable scale. AB then represents the idle kVA. of the factory load. Assuming the efficiency of the synchronous motor to be 91·5 per cent, the power input to the motor will be—

$$\text{kW.} = \frac{\text{h.p.} \times 0{\cdot}746}{\text{efficiency}} = \frac{140 \times 0{\cdot}746}{0{\cdot}915} = 114 \text{ kW.}$$

$$(1 \text{ h.p.} = 746 \text{ watts}).$$

The total load is therefore $670 + 114 = 784$ kW. and the total-load kVA. at 0·9 p.f. $= 784/0{\cdot}9 = 871$ kVA. Then construct the right-angled triangle OCD so that $OC = 784$ and $OD = 871$ to the same scale as before, the angle $COD = \phi_2$ being such that its cosine is equal to the new power factor, namely, 0·9. Then BD gives the kVA. input required by the synchronous motor. In this case it is, by measurement, 240 kVA. Hence from formula—

$$\text{Power factor of motor} = \text{kW./kVA.} = 114/240 = 0{\cdot}48 \text{ leading.}$$

The figure shows that the idle kVA. is reduced from AB to CD, by the addition of the synchronous motor.

OTHER TYPES. The special types of motors recently developed can also be used, such as the "No Lag" and "Kosfi Leading" types. These are cheaper than synchronous motors, but are limited as to maximum size. The "No Lag" type has the advantage that its power factor characteristic can be arranged so that it is, say, 0·85 leading at full load, falling to a low leading value at light loads, so

that it gives more effective compensation than a synchronous motor on a fluctuating load.

(2) Static Condensers. Small condensers can be connected locally across the supply mains at individual motors, or large condensers installed in the power house across bus-bars; but when the latter arrangement is applied, due care must be taken to cut the condensers out of circuit as otherwise they will give rise to a leading current when the low power factor load is shut off, and a leading power factor is equally as bad as a lagging power factor.

To find the capacitance of a static condenser in microfarads μF.) for a given leading kVA., the following formula may be used—

$$C = \frac{\text{kVA. leading} \times 10^9}{2\pi f V^2}$$

Where V = voltage
f = frequency
C = capacitance in μF.

It must be borne in mind that it is uneconomical to attempt to raise the power factor to unity, and usually it is not worth while to raise it above 0·95.

(3) Back-pressure Turbo-alternators. Where process steam is available together with a back-pressure turbine coupled to an alternator, it is sometimes advisable to take the load with the lowest power factor on this set, thus improving the power factor on the remaining load, which takes power from the supply authority. Lighting should not be taken on the set, since it is not inductive and is at unity power factor, and will thus tend to increase the power factor from the supply. A back-pressure turbo-alternator used in this way is shown in Figs. 40 and 41, Chapter II, the rating of the alternator in Fig. 41 being 640 kVA. at 0·6 p.f.

DIRECT CURRENT

Whilst alternating current is generally used for the transmission of electrical energy, there is a number of purposes for which it is not applicable, such as the charging of batteries, heavy-torque or variable-speed motors, etc.; it is, therefore, often necessary to convert the alternating current to direct current. This can be done by means of motor-generator sets, rotary or motor converters, or some form of rectifier.

Motor-generator Sets. When the required output is small the motor-generator set is usually used, but if the d.c. load is fairly large this method is not economical; for since the a.c. energy has to be converted into mechanical power to generate the required d.c. supply, the motor, generator, and mechanical losses must be allowed for. Almost any range of voltage variation may, however, be dealt with, since the apparatus consists of two separate machines. A synchronous motor driving the d.c. generator can, of course, be used with good effect for power factor correction.

Rotary Converters. These serve the same function as motor-

generator sets, but here the motor and generator are combined in one machine. The ratio of a.c. to d.c. voltage is constant and a static transformer is therefore frequently required as part of the set. The a.c. supply is fed to the armature through slip-rings at one end of the shaft, and the d.c. supply is taken from a commutator at the other end. These converters have been developed to an extremely high degree of reliability and, providing proper precautions are taken to prevent reversals of power, are probably the most satisfactory means of providing large amounts of d.c. power, excepting perhaps mercury-arc rectifiers. The chief disadvantage of rotary converters is the expense of maintaining brushes, commutators, and slip-rings in an efficient state.

Motor Converters. These are essentially motor-generator sets in which the rotor of the a.c. induction motor and the armature of the d.c. generator are coupled electrically as well as mechanically. The rotor runs at exactly half synchronous speed, so that voltages of half the supply frequency are impressed on the armature of the d.c. machine, which in effect functions as a rotary converter. The advantages over an ordinary rotary converter are: (1) the stator of the a.c. machine can be wound for high voltages, thus dispensing with transformers; and (2) commutation troubles are reduced, owing to the lower frequency supplied to the d.c. armature. With the present well-developed state of rotary converters there is little to choose between the two, either in reliability or cost, and the selection must be largely a matter of personal preference. Motor converters, however, are unsuitable for outputs of less than 50 kW.

Mercury-arc Rectifiers. These form a modern development and are gradually and surely replacing rotating machinery for d.c. supplies. The principle of the mercury-arc rectifier is that in a high vacuum less than 20 volts is required to maintain an arc between an iron or graphite anode and a mercury cathode, whereas it takes several thousand volts to maintain the arc in the opposite direction. This is due to the fact that the anode, which is fed from a transformer having its primary winding in the a.c. supply circuit, remains comparatively cool whilst the mercury cathode is raised to a high temperature; the d.c. is taken from the cathode and the neutral point of the transformer. The current, therefore, flows freely during the half-cycle in one direction only.

The cathode is in the form of a mercury bath, and the anodes, which are normally composed of graphite, are contained in a glass bulb or steel tank which is exhausted to a high degree of vacuum, the bulb or tank being large enough to allow the mercury to condense. The cathode bath, therefore, is arranged in the bottom so that the condensed mercury can "make up" the cathode losses due to evaporation.

The glass bulb type is permanently evacuated, but owing to the

leakage at joints and to air occluded in the steel, the steel tank type usually requires pumps to maintain the vacuum. The glass bulb type is, therefore, simpler and more suitable for works supply, but cannot be made in large sizes. Several bulbs can, however, be run in parallel, and modern glass technique has enabled larger sizes to be made.

The efficiency of the mercury-arc rectifier depends mainly on the voltage, since the arc absorbs a constant voltage for all types and sizes. It is, therefore, most economical at high voltages, such as those required for traction or the valve anode supplies in broadcasting stations. At industrial voltages it is no more efficient than other types of apparatus, but has the advantage that there are no moving parts, and maintenance is therefore less costly. Other advantages are the ease and cheapness with which remote control can be fitted, and the fact that these rectifiers do not require heavy foundations such as are needed for rotating machinery. The space occupied is also less.

Trouble has been experienced in the past due to "arcing-back," but this is gradually being overcome and the modern mercury-arc rectifier can be considered to be a sound commercial article.

EQUIPMENT

Types of Enclosure. Motors and switchgear are designed for different types of enclosure, according to the conditions in which they have to operate, and it is most important that the correct type should be employed.

The types of enclosures are as follows—

(1) *Protected.* This is the ordinary type for general use.

(2) *Drip-proof.* For use in situations when condensation on pipes or leaks may cause fall of water or other liquids.

(3) *Totally enclosed.* For use in dirty or dusty atmospheres, such as coal-fired boiler houses, carpenters' and joiners' shops, etc., or for use out of doors. Owing to the lack of ventilation, these are larger than other types and hence more expensive. Recently, special types have been developed with an exterior fan and cowling which directs an air stream over the casing in order to cool it, thus allowing a smaller size of enclosure for a given rating.

(4) *Pipe-ventilated.* These are arranged for connection to a pipe or duct, which draws clean air from some region outside the dirty area, and can usually be employed in place of totally enclosed machines, with resulting economy in cost.

(5) *Flame-proof.* These are for use in explosive atmospheres. They are totally enclosed and of heavy construction; the covers are provided with wide flanges so that if any internal explosion takes place, the flames or hot gases are cooled below the flash-point in passing out through the flanges. In oil-filled starters special vents are also provided to allow free exit to any gases produced by arcing

under the oil, the vents being designed to cool down any flames from internal explosions. The frames of flame-proof apparatus are in all cases made sufficiently strong to withstand internal explosions.

It should be noted that a.c. motors of the squirrel-cage type do not need to have flame-proof enclosures, since there is no possibility of internal sparking.

Types of Motors. Before describing the different types of motors available, a point which is often overlooked should be mentioned, namely, the impregnation of the windings. The life of a motor depends very largely on the efficiency of the impregnation which preserves the nature of the insulation. Cheap motors are often inferior in this respect, and it is always well to obtain motors only from reputable makers. Where motors are required for use in corrosive atmospheres such as in plating shops or chemical works, special anti-corrosive impregnation is required, and it is also advisable to specify special paint finish for the frame.

D.C. Motors

With continuous current (d.c.) motors, care must be taken to use the right type of motor for the work it has to do. D.c. motors are of three principal types: *shunt-*, *compound-*, and *series-wound.*

Shunt-wound Motors. In these motors the field coils are wound with fine wire, possessing a comparatively high resistance, which is connected permanently across the mains, thus magnetizing the pole cores and armature with a constant flux. The speed only varies by from 5 to 10 per cent between no load and full load. Speed control is comparatively easy, and is effected by weakening or strengthening the field current by the introduction of a series resistance, weakening of the field producing an increase of speed, and vice versa. These motors are best suited to the driving of small machine tools, etc., where the speed is required to be approximately constant.

Compound-wound Motors. These motors are provided with a shunt field and, in addition, a series field consisting of a few turns of a heavy conductor, through which the main armature current flows. They can be designed for any speed characteristic, either rising or falling with load, the total variation between no-load and full-load conditions being dependent on the amount of series winding provided. They have a good starting torque. They may be either differentially or cumulatively compounded, according as the series field provided by the few turns of the heavy conductor opposes or assists the shunt field respectively.

Series-wound Motors. These have series field winding only. They give a very large starting torque which is proportional to the square of the current, but when the load is released the speed increases indefinitely. To prevent the speed reaching a dangerous figure, they must therefore be under the control of an operator. They are used for traction and for high-speed cranes.

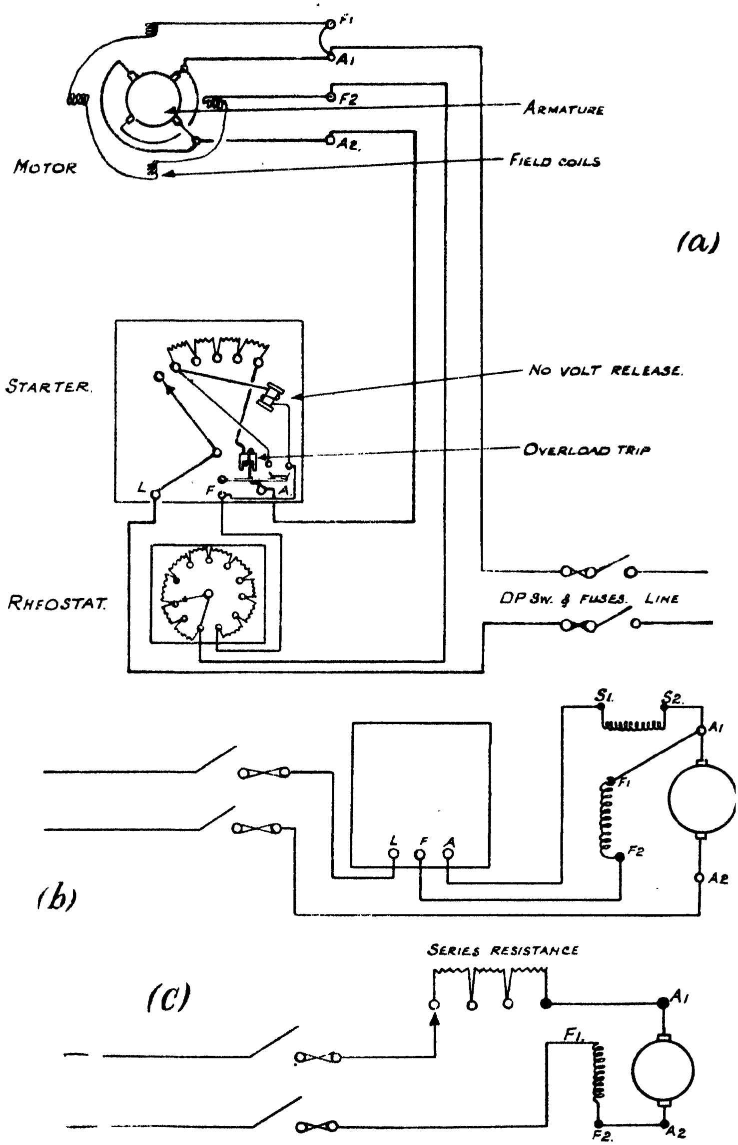


FIG. 113. D.C. STARTER CONNECTIONS
(a) Shunt-wound with speed variation
(b) Compound-wound
(c) Series-wound

Motor Connections. Fig. 113 shows the method of connecting up these types of motors with their starters. At (*a*) is shown a shunt-wound motor with speed variation; at (*b*) a compound-wound motor, the compensating factor in which is the creation of a flux in the series field winding which is intensified at the same time as the armature currents. A series-wound motor is shown at (*c*); the series resistance is usually composed of cast grids connected to a drum type of controller which puts resistance in or out of circuit as loading conditions may demand.

A.C. Motors

There are two chief classes of a.c. motors: *synchronous* and *asynchronous*. The former comprises motors which run at a constant speed dependent on the frequency of the supply, no matter what the load may be. Asynchronous motors comprise *induction* motors and *commutator* motors; they run at speeds which alter somewhat with the load. Induction motors are either of the *squirrel-cage* or *slip-ring* type, according to the form of rotor winding.

Induction Motors. These are the most common type, and owing to their general simplicity of construction and the fact that there is no expense incurred for a commutator, they are also the cheapest. They have a speed characteristic similar to that of a d.c. shunt motor.

Squirrel-cage Type. These are of extremely simple construction, the rotor wires or bars being all connected to common rings at each end, and generally not insulated from the core. In one type of construction, the bars and end rings are of aluminium cast centrifugally into the core, a method which provides an almost indestructible winding, which is, however, only suitable for small sizes.

Squirrel-cage motors require only very simple starting gear, which in small sizes consists merely of a switch connected directly to the line. They possess a characteristically low resistance and low reactance, together with high overload capacity. They have the disadvantage of a small starting torque and are thus most suitable for starting under light loads. The starting torque is only about half the full torque, and to obtain it the starting current may have to rise to perhaps seven times the full-load current. To overcome this, a special type has recently been developed which has two separate rotor windings and gives a starting torque greater than full-load torque with a much smaller starting current; the cost is only slightly increased.

Slip-ring Type. With this type, the rotor windings are connected to three slip-rings—one for each phase—on the rotor shaft. The rotor circuit resistance is not fixed, as in the case of the squirrel-cage motor, since additional resistance can be inserted in the circuit, via the slip-rings. The additional resistance reduces the starting current to a reasonable quantity, and also enables a large torque

to be obtained. The starting torque may be two to three times the full-load torque, the current taken being nearly proportional to the torque. Arrangements can be made to lift the brushes after the motor has started, thus cutting out undue wear on brushes and slip-rings. Resistances in the rotor circuit can also be used for speed variation, but the loss of power in the resistances makes this, as a rule, uneconomical.

These motors are, of course, more expensive than the squirrel-cage type, but are almost essential for large powers, since many supply companies limit the maximum size of squirrel-cage motor which can be installed.

COMMUTATOR MOTORS. (1) *Repulsion Type.* These have similar torque and speed characteristics to d.c. series motors, i.e. the speed rises indefinitely as the load is reduced. They have a very high starting torque (up to seven times full-load torque, with a comparatively low starting current). The most usual type, however, is the *repulsion-induction* type, which combines the high starting torque of the repulsion type with the speed characteristics of the induction type. When the rotor speed has risen to a predetermined amount, all the commutator segments can be short-circuited, so that the motor continues to run after the manner of the induction type.

(2) *Variable-speed Type.* This is a recent development, the speed variation being effected by moving two sets of brush gear relatively to each other. The only starting gear required is the main switch. The standard range of speed variation is 3/1, but these motors can be supplied to give any speed from standstill upwards in either direction of rotation, without the use of any external control gear, a feature which makes them unique. They are, however, somewhat costly.

(3) *Power Factor Correction Type.* (See also page 166.) Another recent development is a commutator type motor with induction motor characteristics, except that there is a leading instead of a lagging power factor. They are more expensive than the induction type, but if a proportion of the largest motors in a plant are of this type, they will correct the bad power factor of the others (as explained on pages 166–7), which will effect a compensating economy. This type in many cases provides the best solution to the power-factor correction problem.

Examples of this type are the British Thomson-Houston "No-lag" and the Crompton-Parkinson "Kosfi." The "No-Lag" type can also be used when a definite speed, different from the standard speeds provided by induction motors, is required, since motors of this type can be designed to run at any speed.

Synchronous Motors. Synchronous motors are merely inverted a.c. generators, and run at a definite and fixed speed depending on the frequency of the supply and the number of poles. As for an alternator, the relationship $N = 120f/p$ holds, where N is the

synchronous speed of rotation in r.p.m., f is the supply frequency in cycles per sec., and p the number of poles. They cost considerably more than other types; but they are valuable when absolutely constant speeds are required, also for power factor correction, since they can be designed to run at any leading power factor. This is arranged, as already stated, by adjusting the excitation, which in turn controls the phase angle. They have a very small starting torque and require special windings and devices for starting; the starting torque is low and starting current is high.

They are relatively much more expensive in the small sizes, and hence the larger sizes only are more generally used. The most common application is that of driving air compressors, and at the same time providing power factor correction. When higher starting torques are necessary, a synchronous induction motor can be used, which combines the higher starting torque of the slip-ring induction motor with the constant speed and power factor correction characteristics of the synchronous motor. This arrangement, however, increases the cost still further. A d.c. supply is then required for excitation, as with the ordinary synchronous motor, this being applied when the rotor reaches synchronous speed.

Single-phase Motors. Single-phase motors are usually only required in small sizes; they present special characteristics. Single-phase induction motors have, strictly, no inherent starting torque, and require special windings and devices for starting; the starting torque is low and starting current is high.

Repulsion and repulsion-induction motors do not suffer from this disadvantage, but are more expensive. These motors possess very good starting characteristics, however, and a power factor of 0·7 to 0·8 is obtainable.

In motors of small sizes, high starting torques are not as a rule required, and many types of single-phase induction motors of the squirrel-cage type exist, which are perfectly satisfactory for ordinary purposes.

High-speed Motors. Most types of a.c. motors suffer from the defect that with supplies at a frequency of 50 cycles per sec., speeds above 3 000 r.p.m. cannot be obtained. The only exceptions are repulsion motors, and the very small motors such as those used for vacuum cleaners, which are usually of the d.c. shunt type running off a.c. This type can be designed to run up to 7 000–9 000 r.p.m. They are chiefly used when a constant torque is needed, and they possess a high starting torque, as well as a high power factor (about 0·9). The full-load efficiency is, however, only about 50 per cent. Since the repulsion type has an unsatisfactory speed characteristic, the provision of very high speeds presents a special problem. Such high speeds are usually required in woodworking shops or for the operation of high-speed drills, and the most modern practice is to install a frequency changer which provides a high-frequency supply

(say at 200 cycles per sec.), either to a separate distribution system, or to an individual machine. To obviate this added expense, special types of induction motors having two rotors have been developed. The outer rotor has a squirrel-cage winding on the outside and a stator winding on the inside, supplied by slip-rings from the mains. The inner rotor, therefore, runs at twice the speed of the outer rotor. They are necessarily large for their output, and the speed variation from full load to no load is double that of an ordinary induction motor, so that they have not been adopted to any extent.

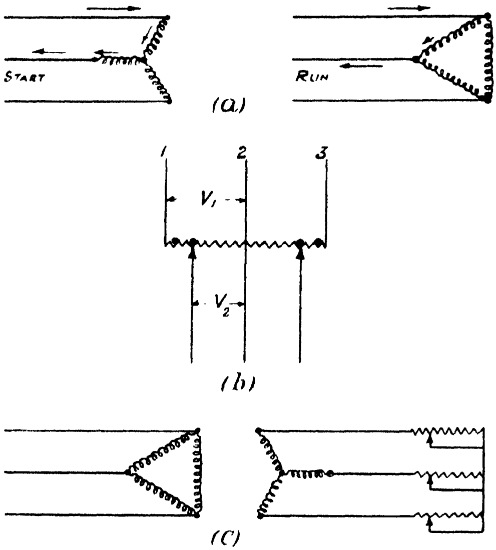


FIG. 114. TYPES OF SWITCHGEAR

(*a*) Star-delta
(*b*) Auto-transformer
(*c*) Rotor Resistance

Built-in Motors. A very interesting development is the incorporation of the motor as part of the structure of a machine tool. For this purpose several manufacturers supply induction motors consisting of a stator shell and a rotor without a shaft; this unit can be incorporated in the machine tool. This saves space and gives a neat appearance.

Change-speed Motors. Where a range of definite speeds is required, induction motors can be obtained which provide several speeds by changing the stator winding connections. In some modern machine tools the speed-controlling change-over switch is mounted as part of the machine, interesting examples being multiple drilling machines having a separate vertical motor driving each spindle directly, with the speed controller mounted on the top end shield of the motor.

STARTERS FOR A.C. MOTORS

The three main systems of starter for a.c. work are (*a*) the star-delta; (*b*) the auto-transformer; and (*c*) the control of rotor resistance (see Fig. 114).

(*a*) **Star-delta.** In this method connections are made to the starting switch from both ends of each phase winding. The switch

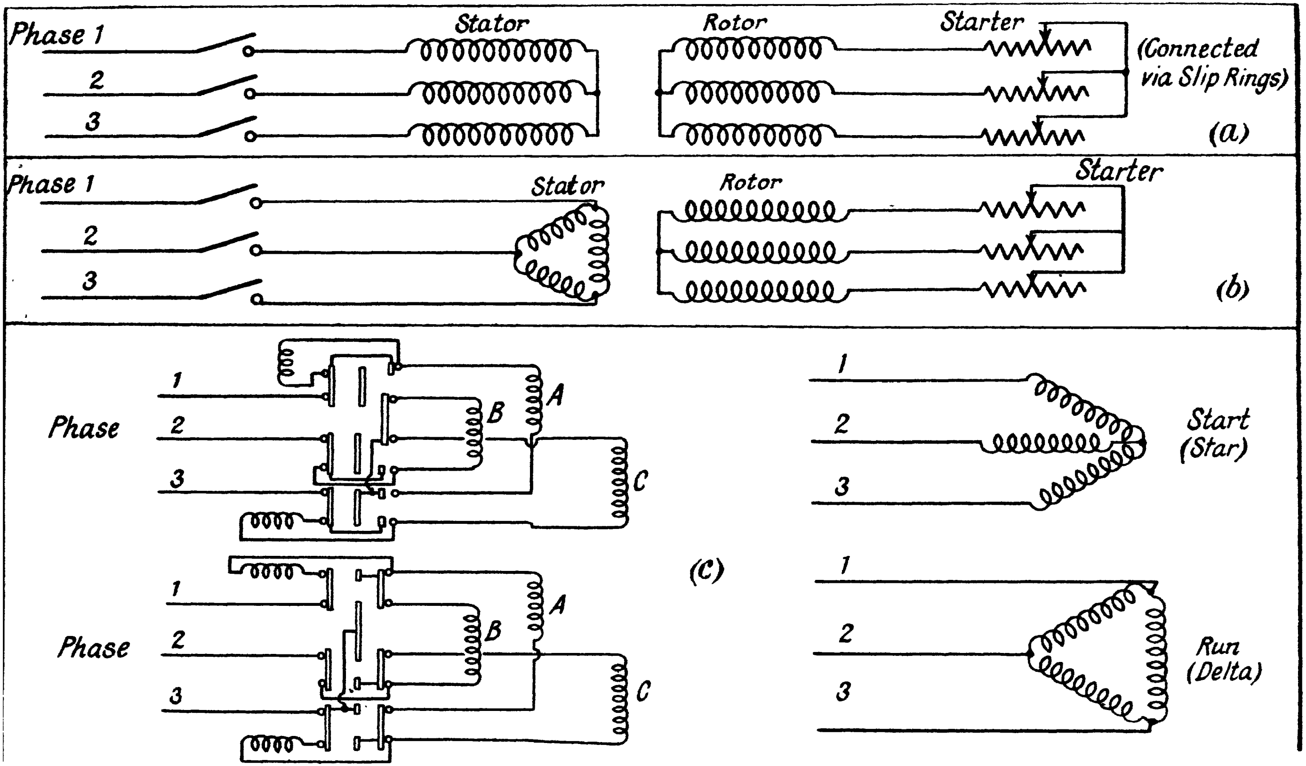
is fitted with contacts so arranged that, after the stator winding has remained star-connected while the motor is running up to speed, the switch can be thrown over to the RUN position and the connections changed to delta (Fig. 114 (*a*)). In the starting position two motor phases are in series between each pair of line wires. This means that $1/\sqrt{3} = 57 \cdot 7$ per cent of full voltage is impressed across each phase, resulting in $33\frac{1}{3}$ per cent full torque. At the running speed, each phase receives full line voltage, and full torque is produced. The method is thus only suitable for starting with a light load. Interlocking should be arranged in the switch so that the delta position cannot be reached without passing through the star position.

(*b*) **Auto-transformer.** An auto-transformer is a special arrangement of transformer components, wherein the primary and secondary windings are not insulated from one another. They are series-connected (see Fig. 114 (*b*)), and the supply is connected across the entire apparatus. One terminal is thus shared by both primary and secondary circuits, whilst the supply system provides the equivalent of the primary current, in the form of a portion of the load current. The remainder of the load current is supplied by that part of the apparatus which is equivalent to the secondary. This method enables various starting torques to be developed, dependent on tappings across the auto-transformer. In the starting position the tapped transformer is placed between phases as shown in the illustration. Very often the tapping shown by trial to give the best results is kept permanently connected up. The switch handle is provided with STARTING, OFF, and RUNNING positions and is operated similarly to a star-delta starter. When the motor has reached a speed approaching synchronism, the transformer is switched out and the motor phases connected direct to line, as in Fig. 115 (*d*).

(*c*) **Rotor Resistance.** In this case the stator is connected direct to the line. This is not harmful, since only magnetizing current is taken for core saturation; the back e.m.f. thereby produced is approximately equal to the line voltage. The action might be likened to starting a d.c. motor by inserting a resistance in series with the armature. It is also open to the same disadvantage, namely, very low efficiency. Its advantage lies in the ability to give any desired speed change.

When the rotor circuit is closed, however, transformer action takes place between rotor and stator, and currents are induced in the rotor, which, since they are within the rotating field produced in the stator, cause rotation. As the speed increases resistance is taken out of the rotor circuit. Generally, approximately 150 per cent normal current is permitted for starting small motors and 200 per cent for larger sizes.

The method of connecting and controlling the motors described above will now be explained.


Phase 1
2
3
Stator
Rotor
Starter
(Connected via Slip Rings)
(a)
Phase 1
2
3
Stator
Rotor
Starter
(b)
Phase
1
2
3
A
B
C
Phase
1
2
3
A
B
C
(c)
1
2
3
Start (Star)
1
2
3
Run (Delta)

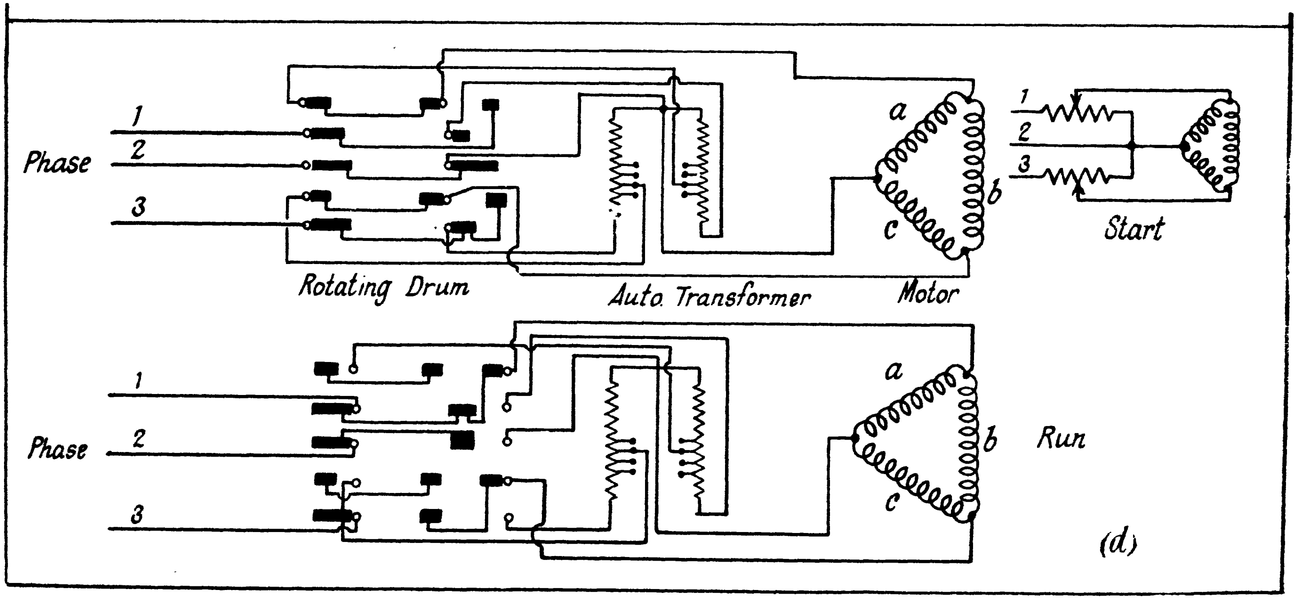


FIG. 115. A.C. MOTOR STARTER CONNECTIONS: THREE-PHASE

(a) Three-phase star-connected
(b) Three-phase delta-connected
(c) Three-phase star-delta starting
(d) Auto-transformer starter

Connections for A.C. Motor Starters. THREE-PHASE. The different types of connection are shown in Fig. 115. The star-connected type is shown at (*a*), the delta-connected at (*b*), and the star-delta system at (*c*). Auto-transformer "start" and "running" positions are shown at (*d*). The star-delta type is the cheapest form of starter, but where heavy starting torques are likely to occur the auto-transformer starter, although more expensive, is the better type to use.

SINGLE-PHASE. Single-phase motors are usually wound with two sets of coils, forming a starting winding and a running winding. The phase-angle is displaced by the introduction of a resistance or inductance, in series with the starting winding, thus producing a rotating field and causing rotation. When synchronous speed is reached, the starting coils are switched out of circuit either by manipulation of the sliding contact arm, or by release of pressure on a "double knob" switch, commonly referred to as a "twin-knob." The circuit is shown at (*a*) in Fig. 115A; means for switching out the coils is shown at phase 1.

TWO-PHASE 4-WIRE. This system is shown at (*b*) and at (*c*) Fig. 115A, with parallel starting; although the latter appears complicated, the circuit is simple in reality. If phase 1 is followed through, assuming the switch is in contact with the winding terminals, it will be found that the top two coils are in series across phase 1. Phase 2 may be similarly treated. A similar condition for these pairs of coils exists when the switch is in the PARALLEL position. The two positions described are, of course, starting and running conditions respectively.

TWO-PHASE 3-WIRE. The connections for these are shown at (*d*) Fig. 115A. It will be noticed that the terminal arrangements of the motors are similar to the 4-wire system. The ends of the two phases are commonly connected to neutral.

Push-button Control. Most starters can be arranged for push-button control; this is a very commendable feature and is becoming universal, especially where the motor forms part of a machine. It enables an operator to start or stop a machine or part of a machine at will, and thus makes for greater safety. The switchgear in this case is operated by means of electro-magnetic contactors which are in turn controlled by the push-buttons marked STOP and START. The contactor type of switchgear is also used on automatic or remote control.

Horse-power Transmitted by Motors. This can be determined from the following formulae—

1 kW. = 1·34 h.p.; ∴ 1 h.p. = 0·746 kW.

Single-phase.

$$\text{B.h.p.} = \frac{V \times A \times \text{Efficiency } \% \times \text{Power Factor}}{746 \times 100}$$

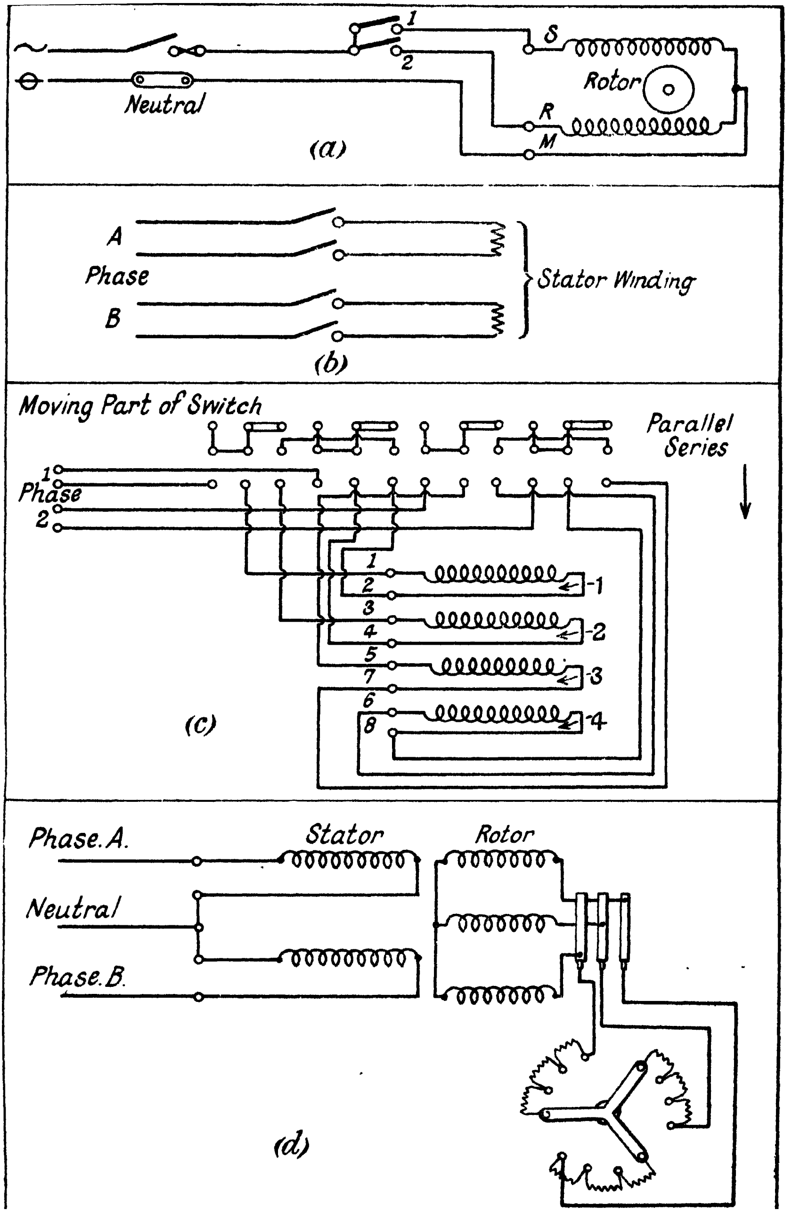


FIG. 115A. A.C. MOTOR STARTER CONNECTIONS: SINGLE- AND TWO-PHASE

(a) Single-phase
(b) Two-phase 4-wire
(c) Two-phase 4-wire with series-parallel winding
(d) Two-phase 3-wire (a wound rotor is assumed in this case)

Two-phase.

$$\text{B.h.p.} = \frac{V \times A \times 2 \times \text{Efficiency \%} \times \text{Power Factor}}{746 \times 100}$$

Three-phase.

$$\text{B.h.p.} = \frac{V \times A \times 1{\cdot}73 \times \text{Efficiency \%} \times \text{Power Factor}}{746 \times 100}$$

D.c. motors.

$$\text{B.h.p.} = \frac{V \times A \times \text{Efficiency \%}}{746 \times 100.}$$

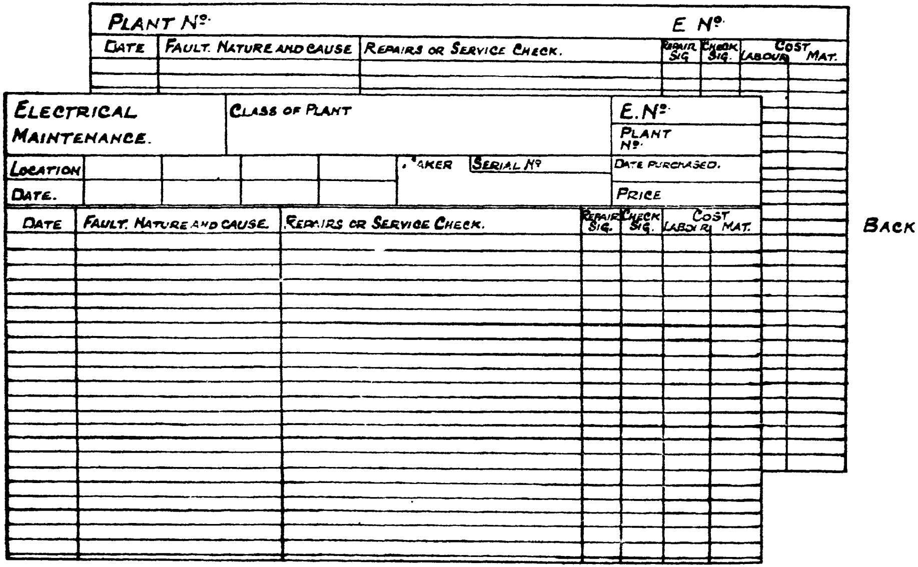
MAINTENANCE

As mentioned earlier, the systematic care and maintenance of the power equipment is perhaps the most important factor in the service department of a works. It is essential that full records should be kept, so that faults may be detected in the early stages, and so that the electricians may be kept well prepared. Layouts of cable runs, distribution boxes, sub-circuits, etc., should be kept up to date; copies should be placed in the plant office and electricians' department, and should be available to all concerned. The same applies to a large circuit diagram showing all power house equipment and wiring, copies of which should be hung in the power house and in sub-stations.

A proper record of each piece of equipment should also be kept. The following system has been successfully used by the author over a number of years. All transformers, high-tension and low-tension panels, alternators, etc., are entered on plant cards and in the plant book, as explained in Chapter I; motors are kept under an "M" number, repairs and costs being treated the same as the other plant. As this method, however, only gives the order number, date of repairs, and cost, an electrical maintenance card as shown in Fig. 116 is also kept, giving the history of faults, repairs, inspections, etc. As it would make the plant book unwieldy if all motor starters, etc., were entered, the latter are registered under an "E" number; a small brass disc about 1 in. diameter is fixed to each starter, with a large "E" and the number stamped on it. The card index is kept in the electricians' department, and is also available to all concerned.

A board with each electrician's check number or initials is placed in a prominent position in the department, and each man chalks thereon the place where he is working. A supply of notices "DANGER: *Men working on mains*" should also be available. Instructions for the treatment of electric shocks should be hung in all sub-stations and in the power house.

Periodic "megger" tests on all cables should be made, also tests for voltage drop when extra load is added to a cable. The recording and checking of consumptions was explained in Chapter I.



FRONT.

FIG. 116. ELECTRICAL MAINTENANCE CARD

The Ohmmeter. The most universally used ohmmeter is the "Megger," made by Evershed & Vignoles. It is a device for the measurement of high resistances (up to 10 000 MΩ.) at voltages ranging from 100 to 2 500 volts. A small hand-operated generator is mounted between the opposite poles of two permanent magnets fixed parallel. Between the other two poles is arranged the movement, consisting of two coils, known as the *pressure* and *current* coils, mounted on a spindle, at a fixed angle to one another. Current from the generator can flow to the circuits of these two coils. No spring control is provided, so that the mutual effects of the coils alone decide the final position of the spindle, to which a pointer is also attached. In the circuit of the current coil is inserted the resistance to be measured. If this is infinitely great, then the pressure coil causes the pointer to move to INFINITY on the scale, as no current will flow in the current coil to oppose this movement. If the resistance is less than infinity, some current will be able to flow in the current coil, bringing the pointer over the appropriate scale reading by setting up a torque which moves back the pressure coil from the extreme infinity setting. The actual scale readings are obtained by calibration with known resistances. The megger has the advantage of being unaffected by variations in the supply, since both circuits are equally influenced by changes in the rotational speed of the generator.

Motors An endeavour should be made to visit each motor once a day, especially when plain-bearing motors are used, to examine the oil level and the condition of the bearings and brushes where necessary, and to remove dust from the bearing covers and machine generally. A feeler gauge should be inserted between rotor and stator once a month to check bearing wear; a general examination of all earthing and insulation conditions should also be made.

In special cases where motors are subject to the action of corrosive fumes, etc., it is advisable to dismantle both stator and rotor periodically and impregnate them with a good-quality insulating varnish, and to paint the inside of the frame with a good acid-resisting paint.

Some firms use a small portable electric blower for blowing dust out of motors and generators; this is useful where there are many machines. Another method is to use a compressed air nozzle, if compressed air forms one of the shop services. If this is done, however, great care must be exercised not to use too high a pressure, or damage may be caused to the windings.

Brush pressure is also an important point, since excessive brush pressure may cause such heat as to be primarily responsible for bearing temperature rise and subsequent seizure. It is a good plan to have a spring balance with a scale calibrated to give readings of the pressures for various sizes of brushes; by hooking the balance on any brush and lifting it so that the latter is just raised, it is possible to determine if the brush pressure is correct.

Self-ventilating motors should be given adequate space in which to act as such, and duct-ventilated motors should draw clean air free from injurious fumes or grit.

In a large works a motor attendant should be employed, whose entire duty is to inspect and oil motors; he should be conscientious and not likely to mind the repetition work.

It is of the highest importance to keep the insulation of motors free from oil. When oiling is done, care must be taken not to allow any oil to work along the shafts of direct-connected generators and so reach the insulation, otherwise a "burn-out" may occur.

Worn bearings may allow an armature to run considerably out of centre, relative to the poles. This is sometimes due to a belt having been unduly tightened, and having thus thrown an excessive load on the bearings. The pulley and belt gear must be thoroughly examined as well as the motor, and preferably at the same intervals.

It is desirable to keep a good stock of spare parts for motors, e.g. spare brushes, insulating washers, carbon tips for circuit-breakers, spare contacts for starting switches and shunt regulators, etc.

BATTERIES

In many works it is necessary to have a steady d.c. voltage, free from machine "noises" such as commutator ripple, etc. A telephone system is an outstanding example, since noises on the d.c. supply would seriously effect communication. Batteries form the ideal means of supply in such cases, but the battery itself may be responsible for noisy communication circuits or varying voltages, if the internal resistance of the battery or its connections is not kept as low as possible. The most commonly used secondary batteries are of the *lead-acid* type.

Lead-acid Batteries. The best method of connecting individual cells is to burn the joint together, care being taken to see that the batteries are not gassing at the time. This operation may be performed with a pointed piece of carbon and a potential difference of approximately 6 volts. A motor car battery makes a suitable supply for lead-burning. Where a number of cells are coupled together to common bus-bars, it is obviously impossible to cut out any that are in comparatively weak condition, so a small booster is sometimes installed to bring the weaker cells up to the level of the others.

In the case of open-top cells, it is desirable to cover the surface of the electrolyte with oil, as this prevents evaporation and saves "topping up" with distilled water. Acid spraying is also prevented. Great care should be exercised in the selection of the oil used, which should be a highly refined paraffin; about 0·065 gal. per ft.^{2} of surface should be allowed. Oil suitable for this purpose is supplied by most battery makers. Its chief drawback is that it makes difficult the taking of hydrometer readings of the acid.

On installing a battery, follow the maker's instructions regarding first charge implicitly, as this is the most important charge of all. In normal service, the battery should be discharged to its lowest limit, and then recharged as soon as possible. Batteries should not be allowed to stand, either charged or discharged, as the plate material becomes inactive due to sulphating. The dynamo used for charging must be a shunt-wound machine, which must be capable of giving a maximum of 2·75 volts per cell. The cells can be assumed to be fully charged when gas is given off freely. The initial charge may take as long as 40 hours. All cells must be connected in series

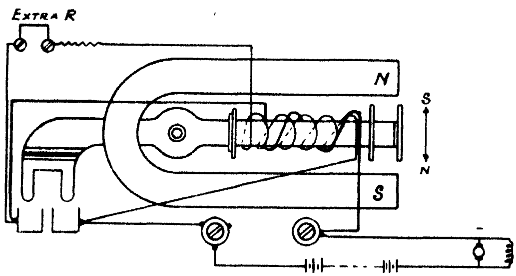


FIG. 117. REVERSE CURRENT CUT-OUT

for charging, with the positive pole of the dynamo joined to the positive plates of the battery.

When charging small cells in inflammable containers, it is advisable to insulate them by placing the cells on rows of porcelain cleats to prevent the charging supply breaking down the insulation of the case to earth, an occurrence which usually results in fire. This danger is most pronounced when charging a large number of cells on a fairly high voltage. A reverse current cut-out, Fig. 117, should be put in series with all charging circuits in case of a failure of the supply. This prevents cells discharging back into the supply circuit. Steps should be taken to prevent dust, etc., falling into cells of the open type. Electrolyte for cells of the acid type should be sulphuric acid of specific gravity 1·200 when the actual filling is carried out, the specific gravity of the acid being 1·843 before diluting with 5 parts water to 1 part acid. The specific gravity when fully charged should be 1·250 and when discharged 1·150. Only pure sulphuric acid should be used. If purchased in concentrated form, it must be diluted by pouring it into distilled water; water must *never* be added to the acid. The containers and stands should be periodically washed down and the spray plates regularly cleaned to prevent the dirt that has collected from getting into the electrolyte.

All metal work and wiring should be kept clean and repainted from time to time with acid-resisting paint or varnish; floors should

also be washed down. A suitable design for a battery room, and the necessity for good ventilation therein, are dealt with under "Buildings," Chapter X.

Batteries must always be fully, *not* partly, charged if they are to have a long life. Accumulation of deposits (sludge), due to metallic particles detaching themselves from the plates when in use and collecting at the bottom of the cells, necessitates that care should be taken to prevent this sediment collecting between the plates, thereby causing a short circuit; should this sediment become very bad, the cells should be thoroughly washed out with clean water and refilled with electrolyte. When fully charged the e.m.f. should be about 2·2 volts per cell. Discharging may take place safely until the e.m.f. has fallen to 1·85 volts (for low rates of discharge) or 1·75 volts (for high rates of discharge). The rate at which plates may be discharged varies with the type of cell, and ranges from 6 to 12 A. per ft.^{2} for capacities of 60 to 36 Ah.

SULPHATING. The formation of lead sulphates is inherent in the process of discharging, but overdischarging may cause an excessive amount to be formed; it should, therefore, be avoided. White patches will also sometimes appear on the plates, particularly on the positive; this substance is an insulator and should be dispersed by giving a continuous charge below the normal rate until the patches disappear. Sulphating can also be caused by too strong a solution of electrolyte.

BUCKLING OF PLATES. This is usually due to a heavy discharge, an undercharge, or short-circuit. Plates should be well supported and suitable separators arranged between them.

Nickel-iron Batteries. These cells employ a non-corrosive electrolyte, a 20 per cent solution of potassium hydrate (KOH). The positive plate is of nickel oxide and the negative of iron oxide. They are almost indestructible and are useful on transport vehicles. It is advisable to change the electrolyte about every 18 months. Reverse charging does not adversely affect these cells, neither does heavy discharge nor neglect. More cells per battery are required for a given voltage, however, because the pressure per cell is not quite so high as in the case of an acid cell. The normal discharge voltage is about 1·2, and the charging voltage about 1·6. The variation between charge and discharge voltage is therefore greater than in acid-filled cells, which is another disadvantage. The filler caps should not be removed except for adding distilled water to make good losses due to evaporation; neither should a naked light be used to examine the interior of the cells.

LIGHTING

Workshop Lighting. Efficient lighting in workshops is one of the most important factors of production. Walls should be painted a suitable colour; overhead gear, such as motors, shafting, hangers,

etc., should be painted, say, aluminium; and windows and roof glass should be kept clean, in order to reduce the light absorption. The light that can be saved in this way, by using daylight instead of artificial lighting over longer periods during the day, is much greater than is generally realized. To cite an example, in the case of roofing glass alone: one sheet of glass in a north-light roof was left for twelve months in a clean district without outside cleaning; it was tested with a foot-candle meter and standard lamp in its dirty state and again after cleaning. The decrease in the illumination, in foot-candles, due to the dirt, was 58 per cent. With electric lighting the saving due to the reflected light from the overhead gear, walls, and ceilings, if these are painted a suitable light colour, cannot be over-emphasized.

The same applies to routine cleaning of lamps and shades and periodic tests for voltage drop on the lighting circuits. The possibility of voltage drop due to the extra load which occurs when lighting is switched on may considerably reduce the efficiency of a lamp; voltage tests should therefore be made under full load.

The *lumen* is the light flux received on unit area on the surface of a sphere of unit radius from a light source of 1 standard candle, situated at the centre of the sphere, i.e. it is the flux emitted in unit solid angle by a point source of 1 candle, the standard candle being the unit of light intensity.* The unit of illumination is the *foot-candle* and is the value of the light produced on a surface one foot away from a standard candle.

For measuring illumination of an installation, such instruments as the "Benjamin Lightmeter," model "B," or the G.E.C. illumination meter, are suitable. They give direct readings in foot-candles; there are no batteries, the meter in both cases being operated by a photronic cell.

For more accurate readings, types such as the G.E. foot-candle meter are very useful; in this case the number of foot-candles is checked against a scale with a standard lamp. The author has used one of this type over many years.

When laying out a lighting scheme, everything depends on the type of building, class of work, etc. For machine shops, foundries, and assembly shops, general lighting is recommended, but for very fine work, such as winding of fine coils, switch-adjusting, or any such work that is likely to cause eye-strain, combined general and local lighting is the ideal arrangement. Individual lighting alone is not to be recommended except in very special cases.

Every care must be taken to eliminate glare, whether it is direct from the lamp or reflected. For machine shop, foundry, or assembly shops with high roofs, general lighting with fittings of the "R-L-M"

* Thus the illumination on 1 ft.^{2} of a sphere of 1 ft. radius from a point light source of 1 candle at the centre of the sphere will be 1 lumen.

type—a standard dispersive type conforming to British Standard Specification No. 232—should be used, the fitting being at a suitable height from the workpeople's eyes in order that the skirt may cut out the glare from the lamp filament. A semi-obscured gas-filled lamp, the glass in the bottom half of which is frosted up to the filament level, will give good results should it be found necessary to carry the fitting higher. Or better still, a fitting such as the "Benjamin Biflector" may be installed.

For general offices, fine assembly shops, and drawing offices, where perfect diffusion is required, industrial diffusing fittings, such as the Glassteel Fitting, may be used with advantage. This comprises a vitreous enamel reflector with a bowl of special diffusing glass. Gaseous discharge tubular lighting, as described in the following pages, should also be considered, especially for very fine assembly work.

Spacing and Height of Fittings. This is decided by the type used, and the following figures are those recommended by the manufacturers—

	R-L-M Fitting			Biflector Fitting				Britalux
Height above working plane (ft.)	6	8	12	6	9	12	15	—
Maximum spacing distance (ft.)	9	12	18	10	15	20	25	As a general rule, height × $1\frac{1}{4}$

The intensity or foot-candles at the working plane must next be considered. The following intensities are suggested—

Assembly shops, rough or medium work	8 to 10 foot-candles
Assembly shops, fine work, combined individual and general lighting	10 to 20 foot-candles
Tool rooms, fine work, combined individual and general lighting	20 to 50 foot-candles
Machine shops, autos, capstans, etc.	8 to 10 foot-candles
Machine shops, fine work, combined lighting	10 to 20 foot-candles
Drawing offices, fine work, combined lighting	20 to 25 foot-candles
General offices	8 to 10 foot-candles

Sizes of Lamps. Having decided on the spacing and height, the area to be covered by each lamp can be calculated; then, if the required intensity is known, the size of lamp can be decided from the chart shown in Fig. 118, which gives Benjamin's figures for the firm's vitreous enamelled reflectors.

Individual and General Lighting. Where general lighting is combined with individual lighting, the intensity of the former may be in the region of 3 to 5 foot-candles, measured in the working plane, whilst for individual lighting the author has found, through

tests made over a number of years, that the type exemplified by the Osram "Daylight" lamp is much more restful to the eyes than the ordinary white lamp. The so-called "daylight" lamp, i.e. with blue glass, has been used for some time in industry for work involv-

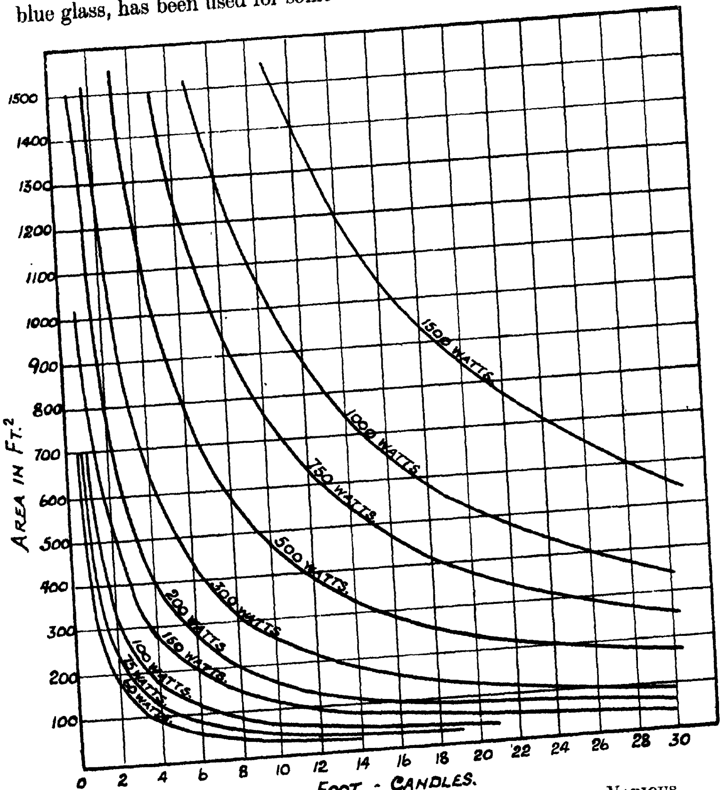


FIG. 118. RELATION BETWEEN AREA AND ILLUMINATION FOR VARIOUS LAMP SIZES

Based on a utilization of 60 per cent

(*Benjamin Electric, Ltd.*)

ing colour-matching, and whilst these lamps are not claimed to be equal to daylight, they do give sufficient colour correction by absorption of the excess red and yellow to permit colour variations to be easily noted.

Their use for individual lighting, however, has not been appreciated. On very fine work, such as switch adjustment, winding of

fine wire coils, etc., where ordinary gas-filled lamps had been used, trouble was experienced due to headaches and eye-strain, and the operators had to resort to glasses, but even this would not cure the trouble. Blue glass was tried, but due to the high light absorption, lamps of higher candle-power were necessary and the heat from this extra wattage was uncomfortable to the operators. Osram 60-watt "daylight" lamps were then tried. At first the operators complained that the light was too "dull," but after getting used to the blue light, some were able to dispense with glasses, whilst complaints regarding headaches and eye-strain became things of the past. Fig. 119 shows different types of reflectors to suit various classes of work. At (*a*) is shown the shade used for winding very fine coils; at (*b*) a type for work involving fine adjustment; at (*c*) another type for a similar class of work; and at (*d*) a pattern suitable for drafting machines. Types (*a*), (*b*), and (*c*) are home-made reflectors painted matt white inside, whilst in type (*d*) an elliptical reflector is used. Figs. 120 and 121 show some of these fittings in use. There is a complete absence of glare with the blue lamp, and fine wires are clearly defined, there being no "fuzziness." The operator is healthier, and, of course, more efficient. Where lamp fittings are within easy reach of operators, and there is a possibility of lamps being taken out of the holders and exchanged or lost, a good method is to fit locking rings so that the lamp cannot be taken out of the fitting without a key. These rings are quite cheap and more than repay their cost. A good type is the "Lamlok." Another good plan is to stamp all lamps of 100 watts or less with a rubber stamp stating "This is the property of . . . Company." For this purpose a special rubber stamp, using a weak hydrofluoric solution, is used. Stamps of this type may be obtained from I. Brook, D.Sc., of London.

Gaseous Discharge Lighting. The gaseous discharge lamp was being used extensively for efficient and economical street lighting before the war; it was also becoming very popular for internal lighting in industry.

The gaseous discharge lamp differs fundamentally from all other systems of light, for whereas all other sources have relied on the radiation from heated solids, in the gaseous discharge lamp the light is produced, not because the vapour in the lamp is extremely hot, but because it is electrically excited.

The standard lamp is composed of a tubular bulb with an electrode at each end, and is filled with a mixture of gases which include mercury vapour, the whole component being enclosed in a tubular glass bulb which is exhausted to a high degree of vacuum. It is thus possible to get a narrow strip or thin "cord" of light about 6 in. long and $\frac{1}{4}$ in. diameter.

The lamp wattage is 400 and the initial light output 16 000 lumens; this light output is $2\frac{1}{2}$ times more than that of the gas-

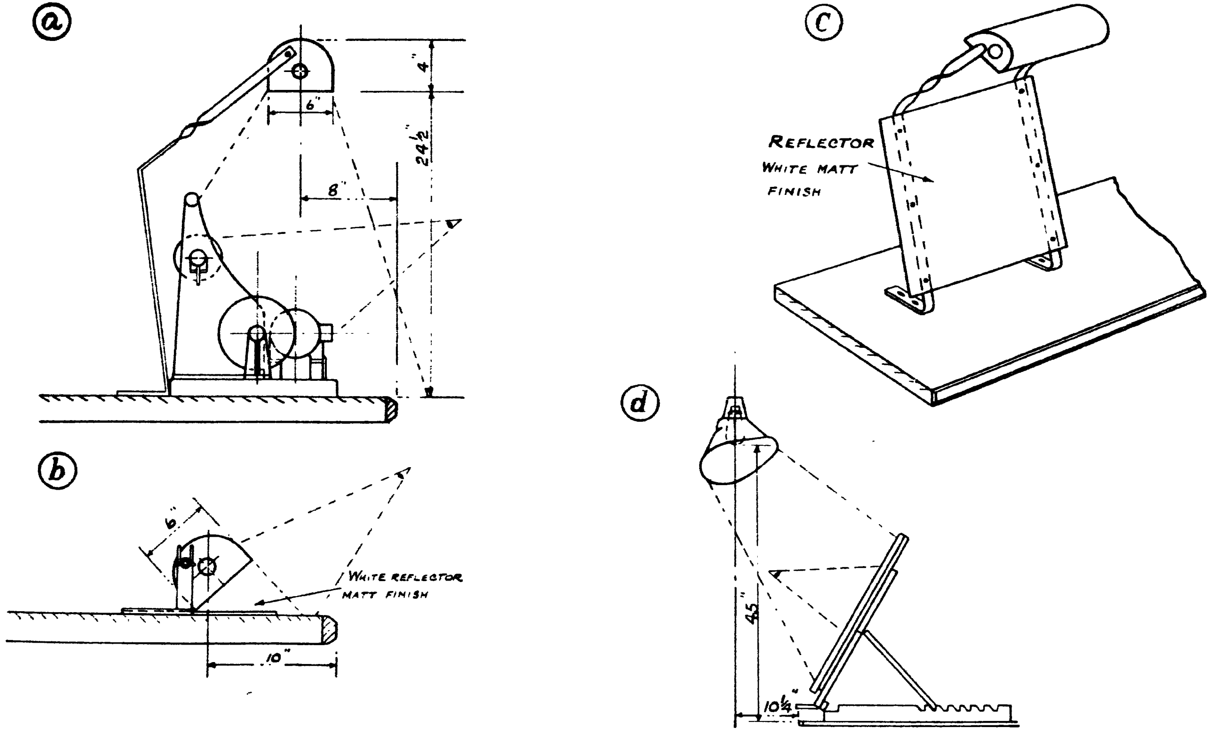


Fig. 119. Reflectors for Various Classes of Work

FIG. 120. USE OF "DAYLIGHT" LAMP ON COIL WINDER
(G.E.C.)

FIG. 121. "DAYLIGHT" LAMPS ADAPTED
TO FINE SWITCH ADJUSTMENT
(G.E.C.)

filled lamp consuming the same energy. The average life of this lamp is 1 500 hr., compared with 1 000 hr. for the gas-filled lamp.

A smaller lamp of 250 watts is now procurable; it has a light output of 8 750 lumens.

The lamp can be supplied for alternating voltages from 200 to 230. Only two connections are required, but a choke is necessary, and a condenser is usually fitted. The circuit is shown in Fig. 122.

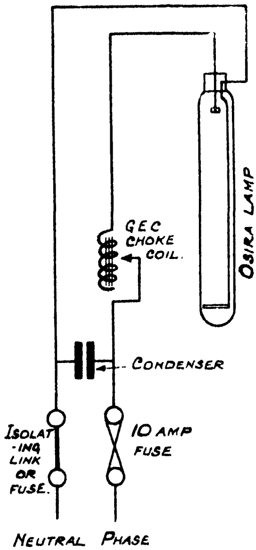


FIG. 122. "OSIRA" LIGHTING CIRCUIT (G.E.C.)

The only drawback to the use of standard gaseous discharge lamps for interior lighting is the colour, which is of a greenish hue, due to the absence of infra-red rays, although a colour-corrected type is now being placed on the market after extensive tests; but where there are high workshops, such as covered ways used for unloading, foundries and heavy assembly shops, it is ideal. Lighting by a combination of gaseous discharge lamps and gas-filled lamps greatly reduces the colour trouble. It has also been tried in some inspection shops with success, but care should be taken where there is moving machinery, as a stroboscopic effect is produced, which makes moving machinery appear to stand still or to slow up. This can be greatly reduced by spreading the lamps over two or three phases.

A more recent development of this type of lamp is the Fluorescent Tube, a tubular lamp about 5 ft. in length, which has been found a real and valuable contribution to increased production in these days of partial or complete black-out in our factories. Its special features are absence of glare and hard shadow, natural white colour, and low power consumption. The "Osram" tube of this type has a nominal wattage of 80 at 200–230 volts, with an initial light output of 2 800 lumens; thus it is nearly equal to a 200-watt tungsten lamp. It is practically shadowless, being a cord of light nearly 5 ft. long, and is thus ideal for fine assembly work. Figs. 123 and 124 show typical applications.

ELECTRIC FURNACES AND THEIR MAINTENANCE

Heat treatment plays such a vital part in modern production that the general conditions and plant are now vastly different from the old dirty environment and crude wasteful equipment which some may still remember. Modern heat-treatment departments should be as clean as an assembly shop, and there should be an

FIG. 123. SHOWING "OSRAM" FLUORESCENT TUBES IN ASSEMBLY SHOP
(*G.E.C.*)

FIG. 124. "OSRAM" FLUORESCENT TUBES INSTALLED IN DRAWING OFFICE
(*G.E.C.*)

entire absence of fumes and smoke, together with ample ventilation, without draught.

It was the advent of the electric furnace which made the designers of gas furnaces realize that great improvements were necessary if they were to compete with electric furnaces, and there is now little to choose between the two types, as far as efficiency is concerned.

The electric furnace is still in its infancy, and improvements are continually in progress. The only materials available at the moment for resistors in uncontrolled atmospheres are varieties of "nichrome" and silicon carbide. Automatic control is now an essential feature in the electric furnace. In many cases, owing to the high thermal efficiency of the furnace, provision must be made to control the rate of cooling. It is essential, where heavy furnace loads are dealt with, to provide heating elements on the sides, roof, floor, back, and door in order to give, as far as possible, a uniform distribution of straight-line radiation. Convection plays an infinitesimal part in the uniform heating of an electric furnace. For many classes of tool work the electric furnace is unsuitable unless the atmosphere of the heating chamber is under control, and even then there are exceptional classes of work that are only entirely satisfactory when done in a gas furnace. For hardening high-speed steel, the electric furnace is ideal, especially when the work is packed in crucibles, as shown in Fig. 125.

It has been found by experience that the steelmakers' usual figure of 1 320° C. is not necessary or desirable for first-grade high-speed tools, and a temperature of 1 220° C. will meet all requirements. Resistance regulators should be avoided where possible, and auto-transformers used instead. A transformer is absolutely essential where silicon carbide elements are used, owing to the ageing of the rods. Salt baths for tempering, etc., can be controlled to 1° C., by means of an efficient transformer. Bus-bar connections are better if they are silver-soldered, with the exception of the joints to the element lead-out. Dry joints give trouble sooner or later, especially if they are always in a warm place.

It is most essential that all contactor switches should be examined at regular periods to avoid any chance of a "stick-up"; and this defect occasionally occurs if the switches are neglected; and as the automatic control does not take care of this, the furnace would heat up until the elements melted if such an occurrence was not noticed.

If the supply is three-phase, every endeavour should be made to balance the load; in fact, if the supply is from a public undertaking it may only be made available on condition that good balance is achieved.

It is a good plan to duplicate all pilot lights, grouping them at a point in the shop where they can all be seen. Switchboard pilots are usually situated where they can only be seen from the front of the furnace, and if anything is wrong it will be noticed far sooner

from a central panel. A cooling bay into which hot work can be run, right outside the furnace shop, adds both to comfort and efficiency.

Should a fault occur with nichrome elements, a new fuse should not be inserted until the elements have been thoroughly examined,

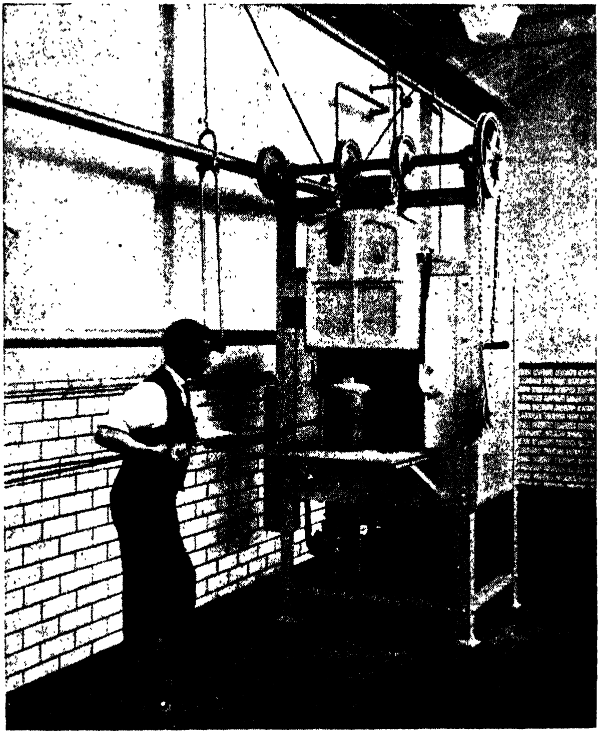


FIG. 125. CRUCIBLE FOR ELECTRIC FURNACE
(G.E.C.)

as an arc can do far more damage than the short-circuit which caused the trouble. If it is necessary to fit a new section to a heating element, an oxy-acetylene torch, using a reducing flame, should be employed. Where high-temperature salt and cyanide baths are used, a light film of graphite on the surface of the bath will entirely eliminate all fumes. A sheet-iron pillar in the shape of a truncated pyramid, loaded in the base with concrete, and put on a "Sorbo" rubber mat (somewhat similar to the pillar shown in Fig. 192 on page 317), makes an ideal anti-vibration mounting for a multi-point temperature indicator.

Standard Furnaces. The standard type of electric furnace is suitable for annealing, normalizing, hardening, heat treatment, carburizing, and reheating, etc. A typical furnace, in this case used for carburizing, is shown in Fig. 126.

Cyanide Hardening Furnaces. The modern cyanide process now supersedes the old method of carburizing with solid compounds, a casing depth of 1 mm. being obtained in two hours. For tool and jig work its advantages will be readily appreciated, not only because of

FIG. 126. STANDARD TYPE ELECTRIC FURNACE
Portable box type for case hardening, reheating, and general heat treatment
(*G.E.C.*)

the much shorter time taken to obtain the case, but also because there is no time wasted in waiting for the work to cool, as in the old process.

Nitriding Furnaces. In this process the case-hardening of special steels is effected by exposing the pieces under treatment to the action of ammonia gas at a temperature of about 500° C. The surface hardness is greater than that obtained by the ordinary carburizing process, and subsequent reheating is dispensed with. It must be understood that a great reduction of machining speeds is essential with these steels, so that the process is only really economical where better wearing qualities are more important than the time required for machining. The equipment necessary for nitriding consists of an electric furnace with automatic control, and a special gas-tight box made in heat-resisting alloy capable of withstanding the action of the ammonia gas at nitriding temperature, fitted with the necessary control valves, etc.

Bright Annealing. Special vertical furnaces are now made to replace the old method of packing in heavy annealing boxes. In other cases special gas-tight enclosures filled with an inert gas are used and electric furnaces are now made to suit this process.

Electric furnaces are also made for the melting of non-ferrous metals and alloys and for vitreous enamelling, etc. There are now also ovens for stoving general electrical work which is impregnated with various varnishes and synthetic resins, as well as ovens for core drying, etc.

Control. The potentiometer type of control such as that made by the Cambridge Instrument Co. and the Leeds and Northrup Co. of America, are good examples of what can be done in the way of automatic control. A temperature variation of less than 2½° C. is easily possible.

SAFETY

Owing to the danger of electric shock, it is essential that proper precautions shall be taken when installing and operating electrical plant. The Home Office issues stringent regulations as to the types of plant which may be used, also methods of installation, cabling, earthing, etc.; and if trouble is to be avoided, no plant should be installed without consulting the regulations. When buying apparatus it is essential to specify that it shall comply with Home Office regulations, as there is unfortunately still a small number of firms marketing such items as distribution boxes, motor starters, etc., which do not conform to the regulations.

All frames and covers must be efficiently earthed. For this purpose it is necessary to provide earth cables or strips, which should be of ample cross-section and should be connected to an efficient earthing system. It is not sufficient to rely on the steel structure of buildings, since the steelwork is usually bedded in concrete, which is a partial insulator. The type of earthing system which is necessary depends on the kind of soil, and in this connection recent research shows that the usual type, using a large bent plate, is not generally the best. The best type for most soils is a system of 2 in. pipes, from 6 to 7 ft. long, driven in at least 6 ft. apart, the number necessary depending on the size of the works. Connections should be made above ground, so as to avoid corrosion of the contacts, and the soil should be kept damp, preferably by placing the system near a drain spout. In soils of high resistance the conductivity can be improved by treating it with salt or washing soda. This need only be done about every six months by digging holes above the earthing system, and filling them with salt or soda, which should then be covered with earth, to prevent rain from washing it away too quickly.

The earth wires and cables should be regularly tested for conductivity, and the resistance should also be checked occasionally in order to ensure that connections are tight and that corrosion has

not deteriorated them. If this is not done there is no means of knowing that the earthing system is sound.

Where a high-voltage supply is obtained from an outside source, the high-voltage switchgear and transformers must be adequately protected; and if a metal-clad system is not used it is essential that all the doors of switch cubicles, etc., should be locked and the keys kept by a person in authority, who should only issue them to competent authorized persons as required. Any work carried out must be under this official's personal supervision.

A point which is often overlooked is the earthing of lighting systems. If one line of a lighting supply is earthed, the lighting switches must be placed in the earth line. If metal lamp-holders and fittings are used, they must also be earthed. The number of accidents which still occur due to non-observance of these two simple regulations is surprising. All small lamp-holders, especially if within reach of operators, should be of insulated construction.

In works having high-voltage lines, an assortment of useful articles should be kept ready for use in emergency, as, for example, when a person has accidentally come into contact with a live conductor. (The difficulty, of course, is always for the rescuer to avoid becoming a victim also.) Rubber mats which the rescuer can use to stand on, and rubber gloves, together with hooked sticks having handles of ebonite, are very valuable at such times; and if they are kept handy, near exposed conductors and similar danger spots, they may help to save a life at a time when every moment is precious.

A combined outfit with rubber mat and gloves in a suitable container is made by F. Woodhouse & Co., London. The gloves are periodically tested free of charge.

CHAPTER V

MILLWRIGHTING AND MACHINE TOOL REPAIRS

Millwrighting. Whilst this section is primarily concerned with the installation or removal of plant, belting, lubrication equipment, shafting, etc., it is sometimes advisable to bring joiners under this department, especially when removing work benching, bench machines, tool and store racks, etc., as by so doing the responsibility is put on to one foreman. The author has found this a very satisfactory arrangement.

The necessary records of the installation of machines were dealt with in Chapter I, and it should always be understood by the millwrights that the brass plate, with the plant number stamped on, should be fixed to the machine before leaving the job. In some works it is the practice to paint the numbers on the machines; but not only is this more costly, but in time the number becomes illegible due to oil stains, or to the paint being rubbed off. A good size of brass blank to take numbers up to four figures is $2\frac{1}{8}$ in. × $1\frac{3}{16}$ in., having two holes punched to take $\frac{1}{4}$ in. Whitworth snap-headed set screws. A set of $\frac{3}{8}$ in. figure stamps should be kept in the department.

Emergency Tool Chest. For breakdowns or emergency use, a breakdown locker or chest should be kept, in which the usual tools —hammers, wedges, saws, scrapers, and a range of files in new condition—are kept, so that should a breakdown occur after normal working hours, when the stores are closed, this locker can be taken to the job and the repair started in minimum time. An inventory of all tools should be pasted in the lid, and the contents of the box checked after use by the chargehand, replacements being made where necessary.

Lifting Tackle. All chains, slings, and lifting blocks should be numbered and kept in special stores, to which they are returned after use. They should be inspected and oiled once a month by a millwright detailed for the job and the work entered on a sheet, as shown in Fig. 127, which is sent to the Plant Office for filing. Periodic annealing of all chains should be carried out and recorded. This is compulsory under the new Factories Act, 1938.

Useful Millwrighting Equipment. Sketches of useful equipment are given in Fig. 128 (on page 203). At (*a*) is shown a useful 2-ton lifting truck, and at (*b*) a hand crane; (*c*) is perhaps one of the most useful tools, a 12-ton Tangye hydraulic jack, which weighs 90 lb., is only 10 in. high, and is invaluable for lifting or pushing machines into position. A handy shafting truck is shown at (*d*); this can easily be made up from 4 in. × 2 in. channel, whilst (*e*) shows an electric hammer for cutting out small foundation holes.

POWER TRANSMISSION AND DRIVES

Belting. This is one of the materials of which petty pilfering or waste is most likely to take place, and a systematic check is necessary. A good scheme is to have a belt record book. The belt man keeps a small stock of the smaller belting, which he draws from the stores. When belts are replaced, the foreman of the section con-

MONTHLY REPORT ON CRANES, HOISTS, LIFT VANS, LIFTING TACKLE, ETC.

Section 4. MILLWRIGHTS. Month ending May. 1934.

No.	Description	Capacity	Repairs	Inspection	Inspn. by	Date
1.	Travelling Crane Section 6	5 Tons	Oiled + Greased	O.K.	[illegible]	8/5/34
2.	Electric Hoist Section 8	1 Ton.	Oiled + Greased Ropes inspected	O.K.	[illegible]	18/5/34
3	Morris Blocks	3 Tons	cleaned + oiled	OK	[illegible]	28/5/34.
4.						
5						

The following chains annealed Nos. 5, 7, 12

FIG. 127. INSPECTION SHEET FOR LIFTING TACKLE

cerned signs the belt book (in which is inserted the appropriate machine number and the size and length of belt supplied), the cost being charged to his section. In this way the belt man is able to account for all belting drawn by him from the stores. Large belts are drawn direct from the stores by the belt man and entered in the same way. Both the belt man and the storekeeper have a stamp, with which they stamp the end of the roll of belting, so that they can tell immediately if their stock has been tampered with. From

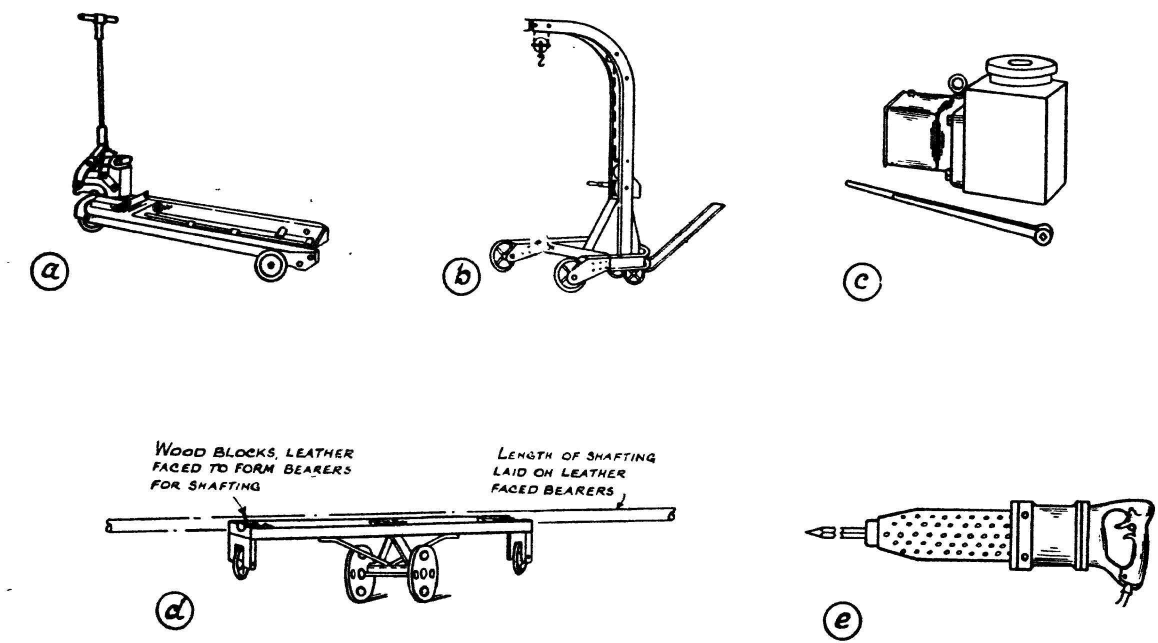


FIG. 128. USEFUL MILLWRIGHTING EQUIPMENT
(a) Elevating truck (b) Portable jib crane (c) Hydraulic jack (12 tons) (d) Shafting trolley (e) Electric hammer

the belt book it is also possible to check the life of different types of belting.

Over a number of years, the author has found that with flat belts for general use, a good hide belting, such as "Columbia," gives the longest life. Laminated belting can be used on a clean drive and where the pulleys are rimless.

On drilling machines where round belts have to pass over jockey pulleys at high belt speeds, the Scandinavian belt is perhaps the best. A life test made by the author over 116 belts, with an average speed of 1 590 ft. per min., showed 38·64 months of life per belt.

For round belts on drilling machines, those supplied by Leland Gifford give a fairly long life, the average on 82 spindles, taken over several years, being 14·2 months per belt.

Where speeds above 2 000 ft. per min. are necessary, longer life and less belt slip will occur with a hide "V" belt. Tests made with an $8\frac{3}{8}$ in. driver and 2 in. driven "V" pulley, at a belt speed of 3 370 ft. per min., proved that there was a definite slip with a $\frac{3}{8}$ in. round belt, but with $\frac{3}{8}$ in. "V" Columbia hide belting the slip was practically eliminated. This check was made a number of times with the aid of a rotoscope.

Balata belting is sometimes the most suitable type for use under special conditions. It has a very low stretch, and is proof against water, dampness, and steam, whilst it will withstand *dry* heat up to about 110° F. It has great strength, and will resist the action of grit and dust well, but is adversely affected by mineral oil. Balata belting is therefore suitable for use in a damp or steamy atmosphere, or out of doors, and for grinding machinery or in dust-laden air. It is not suitable if acid fumes are present.

Transmission Losses. The power lost in transmission may be due to the belt being either too tight or too slack: in the former case the loss is due to the extra friction on bearings, etc.; whereas the latter is due, of course, to belt slip. A belt should just be tight enough to drive without slip, the slack side being on top. Belting is impregnated with a tissue-lubricating medium during the curing, which may become dried out if the belting is in stock for a long time. In this case, some sort of dressing should then be applied before putting the belting into use, castor oil being perhaps the best. Dressing must always be applied evenly over the surface of the belt. When belts become saturated with oil on such machines as automatics, a good method of cleaning is to use a trichlorethylene degreasing plant, if one is available, applying the process as for metal parts. Where this plant is not available, cleaning may be carried out with a rag saturated in petrol or naphtha; french chalk, rubbed in, is also a good method provided the belts are not too oily. The french chalk should be scraped off when it has absorbed most of the oil.

Camber of Pulleys. A curve showing the recommended camber for pulleys of various diameters has been prepared, and is reproduced here (Fig. 129) by permission of Messrs. John Tullis & Son, Ltd., of Glasgow. The firm, as belting manufacturers, point out that wrong pulley camber is one of the principal causes of belt troubles. The camber should not exceed $\frac{3}{32}$ in. for large-width pulleys, or $\frac{1}{32}$ in. for small-width pulleys. The ideal pulley should

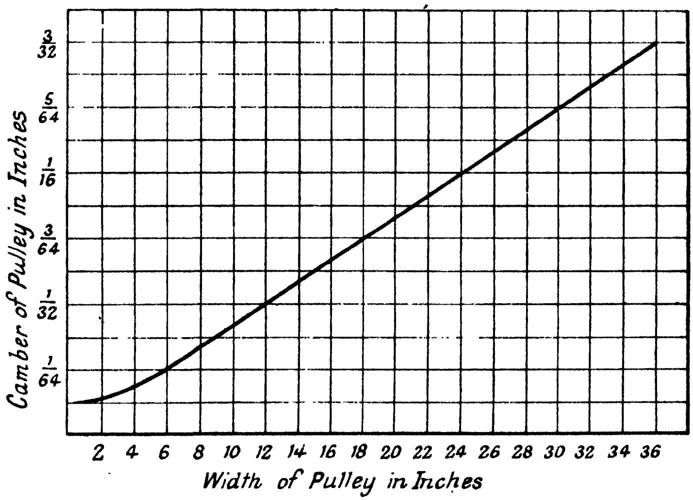


FIG. 129. RECOMMENDED CAMBERS FOR CAST IRON TURNED PULLEYS
(*John Tullis & Son, Ltd.*)

be perfectly flat; but, owing to slight irregularities in alignment of shafting and pulleys, it is found in practice that a slight camber gives better results in keeping the belt in the centre. Excessive convexity causes slipping by reason of potential differences in velocity of periphery at the centre of the belt and at its edges; but as there can be no actual difference in velocity, there must be a difference in the strain between the centre of the belt and its edges. The higher the crown, therefore, the more these differences are accentuated.

H.P. Transmitted by Belting

$$\text{Width of the belt} = \frac{\text{H.P.} \times 33\,000}{\text{S} \times \text{C}}$$

$$\text{H.P. transmitted} = \frac{\text{S} \times \text{W} \times \text{C}}{33\,000}$$

where S = Speed in ft. per min.

C = a constant = 50 for single-ply belts, and 80 for double-ply belts.

W = Width of belt, in inches.

Method of Calculating Length of Belting Required

Let D and d be the pulley diameters.
,, C ,, distance between pulley centres.
,, L ,, length of belt required.

For Open Belt—

$$L = \frac{3{\cdot}14\,(D + d)}{2} + \frac{(D - d)^2}{4C} + 2C$$

For Crossed Belt—

$$L = \frac{3{\cdot}14\,(D + d)}{2} + \frac{(D + d)^2}{4C} + 2C$$

Group and Individual Drive. This is a very controversial point, and every case must be considered on its merits; everything depends on the class of machine.

For woodworking machinery, where high speeds are necessary, the motorized machine is the ideal arrangement, even if frequency changers are necessary to get the required speed; but where there are batteries of small machines, such as drills, small capstans, etc., the belt drive is advisable, as this enables provision to be made for

	Makers' Recommended H.P. per Machine	Actual No. of Machines on 2¾ in. Lineshaft	H.P. of Motor Driving Lineshaft
No. 1 Warner & Swasey Capstan	1	50	25
No. 2 Warner & Swasey Capstan	1½	29	25
No. 4 Warner & Swasey Capstan	2	27	25
No. 6 Warner & Swasey Capstan	3	18	25
No. 2 Herbert Capstan . .	2	27	25
No. 0 Brown & Sharpe Autos .	2	20	25
No. 0G Brown & Sharpe Autos .	3	14	25
No. 00 Brown & Sharpe Autos .	2	24	25
No. 00G Brown & Sharpe Autos	2	20	25
No. 2 Brown & Sharpe Autos .	3	14	25
No. 2G Brown & Sharpe Autos .	3	14	25
Index O Autos	2	17	25
Index OD Autos	2	17	25
Index 12 Autos	2	17	25
Index OR Autos	3	10	20
Index 18 Autos	2	12	20
Index 24 Autos	3	12	25

a wide range of speeds, whilst on the other hand the cost of installation and maintenance is less. There can, however, be no hard and fast rule.

Where several machines are to be driven from one line-shaft, it is difficult to estimate the horse-power of the motor required. Machine tool makers' figures are always on the high side, as they allow for the peak on the individual machine plus a good margin of safety. The actual load will depend on the class of work, but the figures shown in the table on page 206 will serve as an indication allowing for medium-class work on different classes of well-known machines.

From these figures it will be readily understood that with individual drive to these machines, the motors would be only running at half-load for the greater part of the time, as obviously the size of motor for individual drive would be determined either by the starting load or peak load, whichever were the greater. This method of reckoning would result in a very low electrical power factor, which must be improved either by the use of condensers or by some other means of power factor correction.

With individual drive, the capital outlay for a number of small individual motors, as against one large motor and shafting, will also be considerably more. Against this, by reason of the absence of shafting and belts, the machines are generally safer for the operators; also, unless very great care is taken in the layout of machines, shafting, and belting both daylight and artificial lighting will be considerably reduced.

It will, therefore, be understood that the method of driving any particular battery of machines can only be decided by analysis of the economic factors governing the particular case. In most large works to-day, both individual, small, and large group drives are simultaneously in use, proving that each case must be dealt with on its own merits.

Shafting. All shafting should run on ball bearings. Plain bearings should not be used. Apart from adjustments and the necessary oiling, etc., the frictional losses due to plain bearings are alone enough to condemn them. The deflection of power-transmitting shafting should not exceed $\frac{1}{100}$ in. per ft. length, and the bearings should be spaced to ensure that this condition is fulfilled, otherwise endless trouble will occur with overheating or seizing of the bearings. Driving pulleys, clutches, or couplings should never be placed midway between bearings, where the maximum deflection occurs. The tendency is towards larger-diameter shafting, with ball bearings, but it will be found that the diameters recommended by manufacturers can in some cases be slightly reduced. As an example, for 10 ft. centres, the recommended size is 3 in. The author has in use some thousands of feet of $2\frac{3}{4}$ in. shafting, which has given no trouble whatever over a number of years. Table XIII gives the diameters recommended by the Hoffmann Company, but these figures are

TABLE XIII

SUITABLE PITCH FOR LINE AND SHAFT BEARINGS AT VARYING SPEEDS

(As Compiled by Hoffmann Manufacturing Co., Ltd.)

Speed of Shafting in R.P.M.	Diameter of Shafting in Inches													
	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$
	Average Pitch of Bearings, Centre to Centre (Feet and Inches).													
300	5 9	6 6	7 0	7 6	8 0	8 6	9 0	9 6	10 0	10 6	10 9	11 3	11 6	11 9
450	4 9	5 3	5 9	6 3	6 9	7 0	7 6	7 9	8 3	8 6	8 9	9 3	9 6	9 9
600	4 0	4 6	5 0	5 6	5 9	6 0	6 6	6 9	7 0	7 6	7 9			
750	3 6	4 0	4 6	4 9	5 0	5 3	5 9	6 0	6 3					

The above table is calculated for an ordinary disposal of pulleys along the shaft.

conservative, and centre distances can be increased from 1 ft. to 18 in. Ball-bearing shafting, if properly installed, needs very little attention; in fact, overhead shafting under normal conditions should only require greasing about once a year. The ball-bearing manufacturers have placed some excellent hangers on the market, but unless they exactly fit individual requirements, it is advisable to have patterns made of a type of hanger which can be instantly fixed with hook bolts to the overhead steelwork; this may mean two or more types of fixing, but providing the method of attaching the bearing housing is standard, it will more than repay the expenditure. Roller bearings have been employed in cases of very heavy loading.

Plummer Blocks. These should always be of the ball-bearing type for light and medium loads, for the reasons already given. Ball-bearing manufacturers make a variety of sizes and shapes to suit every type of work.

Couplings. Shaft couplings of the flange type, with long sleeves, are not always satisfactory, as, in the event of a slight variation in the shaft diameters, the sleeve will have a tendency to slip on the smaller diameters. A type with a separate sleeve for each shaft will be found to give the best results; when the flanges are tightened, the compression is uniform on each shaft.

Other types of couplings which might be mentioned are—

(*a*) The *rubber buffer* type, in which rubber buffers on steel pins transmit the power from one flange to the other.

(*b*) The *multiflex* or *Bibby* type, consisting of two flanged discs, one having inwardly flared grooves cut in the peripheries; the two discs are connected together with steel connecting rings.

(*c*) The *chain-coupled* type, consisting of two chain sprockets coupled together by a length of duplex chain.

Motor Drives. For years the inverted-tooth chain drives have been used for driving shafting and, whilst they have given good results, they are gradually being superseded with the "V" rope drive. With the chain drive, oiltight chain casings were necessary; oil levels had to be maintained, and at the end of five years it was necessary to have the chain re-pinned, after which it lasted two to three years. With the "V" rope drive, such as the "Texrope," the ropes will outlast the chain and can be replaced in a very short time; no oiling or chain cases are necessary, and only a simple belt guard is needed. A drive for a 20 h.p. motor is shown in Fig. 130. In this particular example, the makers claim a 94 per cent effective pull, at the same time decreasing the load on the bearings by 50 per cent. These ropes are now often made of rubber, which provides several advantages, such as shock-absorbing qualities with pulsating loads, or with a damp or steamy atmosphere, or where silence is essential. An obvious advantage is that if a single rope breaks, it is not imperative to shut down the machine or driven shafting instantly, as

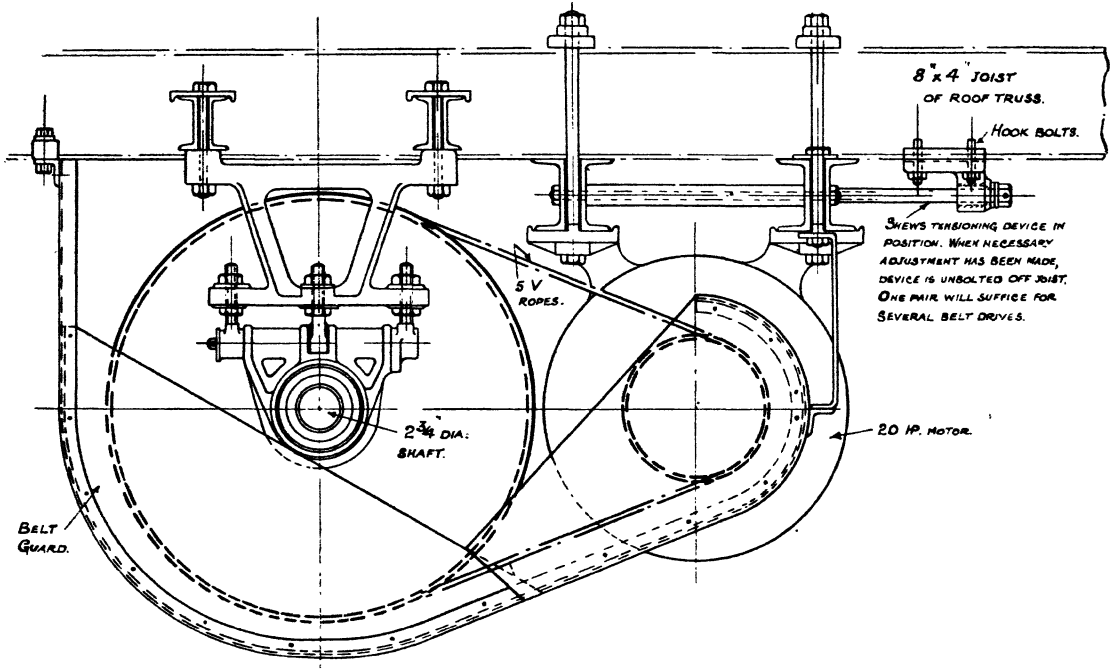


FIG. 130. "V" ROPE DRIVE FOR 20 H.P. MOTOR

the remaining ropes would probably be able to continue for a while. A drive transmitting 250 h.p. is shown in Fig. 131.

Painting of Overhead Gear. All hangers, couplings, motors, and belt guards should be painted aluminium. The extra light gained in the shop, especially if it is a north-light roof, has to be observed to

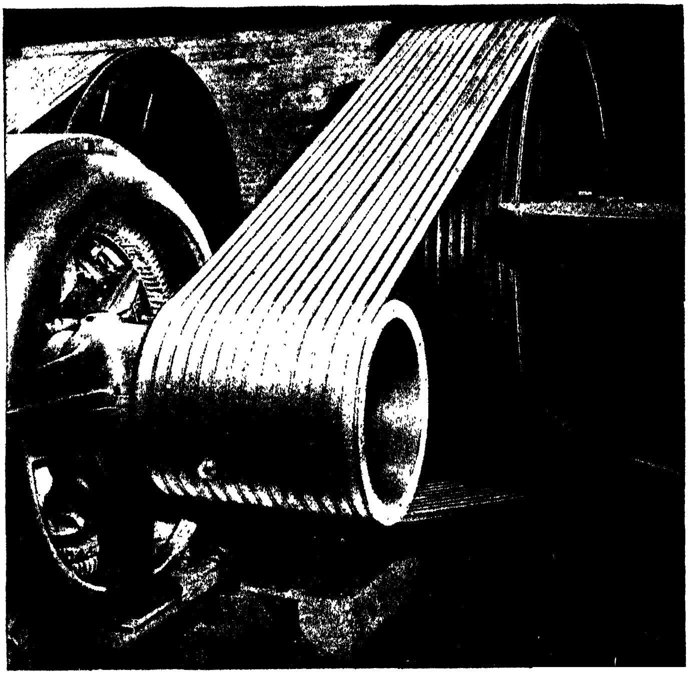


FIG. 131. 250 H.P. TEXROPE DRIVE
Induction motor driving pulp beaters
(Frank Wigglesworth & Co., Ltd.)

be appreciated; moreover, the artificial lighting cost will be greatly reduced.

Oiling and Greasing. Oil should be kept in proper cabinets and labelled with the class of work for which it is intended; a cheap and effective oil cabinet, such as that made by the "Wesco" Products Company, Birmingham, is shown in Fig. 132. Wastage is reduced to a minimum and there can be no mistake as to the class of oil. There is a tendency to mix two classes of oil to suit a particular job, but this is not advisable, as the two types of oil will in most cases separate if not properly blended. The supplier will give advice on a suitable class of oil for the particular case. Wherever possible, oil should be reclaimed by heating and passing through a centrifugal separator.

Oilmen's hours should be arranged so that they can carry out the dangerous oiling whilst machinery is stopped, e.g. by arranging for them to start an hour or two before normal hours and to finish earlier. They should also work during the normal dinner hour, taking their meal hour either before or after.

Loose pulleys are sometimes difficult to lubricate. Any device

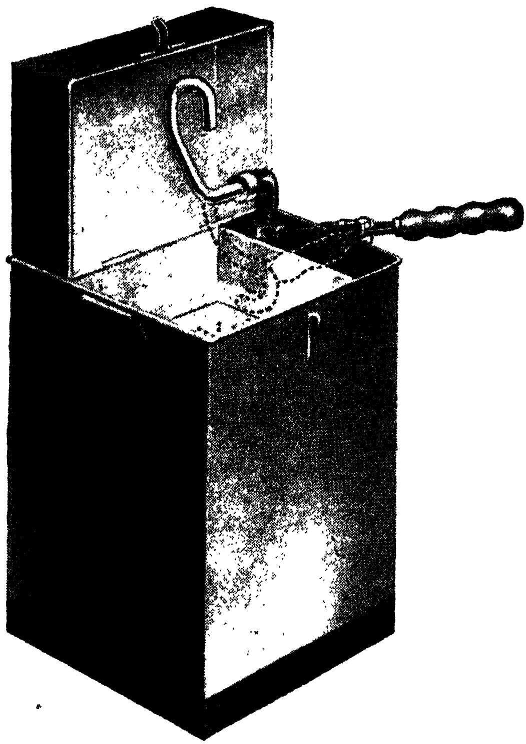


FIG. 132. "WESCO" OIL CABINET
(A. E. Westwood, Ltd.)

attached to the hub will be liable to the action of centrifugal force tending to fling the oil outwards from the surfaces to be lubricated. A compression grease cup is a suitable remedy; it is provided with a spring which continually forces the grease into the bearing.

For lubricating ball bearings, special grease is generally preferable to oil, since grease of the right consistency does not tend to find its way out of the housing; hence it does not need such frequent renewals. The correct consistency should be a little stiffer than that of vaseline. The grease should contain no abrasive, nor any graphite,

and should have a mineral base, not animal or vegetable. For speeds of 300–1 500 r.p.m., renewals sometimes may not be required oftener than once a year, the frequency being really dependent on the tendency of the grease to dry out. New grease should be pumped in with a "gun" until some of the old grease is displaced and forced out of the bearing.

REPAIR STAFFS

Carpenters and Joiners. Where only a few men are kept for maintenance work, there is a tendency to furnish them with only a few old machine tools. A small number of well-chosen machines can, however, save hours of work which would otherwise have to be done by hand. The following equipment is suggested—

A saw bench having a table about 39 in. × 18 in., arranged with a chuck for taking drills.

A Wadkin universal saw, motor-driven.

A 6-in. hand-feed electric planer.

A larger planer (which may be purchased second-hand) and a thicknessing machine are also useful.

A motor-driven mortising machine.

Wherever possible, benching, racks, etc., should be standardized; bench legs should be of cast iron and should be made from a standard pattern. By so doing, it is possible to make up lengths of benching at short notice, bolts of the sizes required and everything necessary being kept in stock. If this is done, it is possible to estimate accurately the cost of proposed work.

Patternmaker. Where the class of manufacture does not necessitate the use of a foundry, the patternmaker should come directly under the control of the Plant Office, so that he can work directly with the draughtsmen on any particular job; this arrangement saves much time and expense. He should work near the joiners' shop, so that he can use their machines, and should have a wood-turning lathe, marking-off table, etc., in his workshop.

He should be responsible for all patterns and their storage, the patterns being numbered and stored on shelves, after being indexed under a card-index system. The appropriate number is allocated in the Plant Office from the Pattern Book, which should be cross-referenced with the number of the drawing of the particular article. (Pattern numbers should be marked on all drawings.)

It frequently happens that the pattern shop is a comparatively small department of the works, and the men may spend a large proportion of their time repairing patterns, so that operating expenses are apt to be considerable. In such cases it is preferable to adopt a different time-keeping system from the other departments, issuing the men daily with special time-cards containing various headings against which the hours spent in the different classes of work are entered. A blank space is provided for entering any other

non-productive work and the time spent thereon. The foreman pattern-maker is responsible for the time allocations on the cards, and has to see that the time is properly distributed.

The numbers should always be clearly marked on the pattern so that they are easily distinguishable in the casting. If metal letters and figures are used, they should be firmly fixed to the pattern. To form a radius on a pattern, wax strips, such as those made by the Kindt Collins Co., Cleveland, Ohio, U.S.A., may be firmly fixed by the use of a heated metal former or "iron." Where patterns are subjected to a great deal of use, it is advisable to cast a metal pattern; this can be fettled up and will last for years.

Shrinkage of Patterns per Foot Length

Cast iron	(beams and girders)	$\frac{1}{10}$ in.	Thick brass	$\frac{5}{32}$ in.
,,	(large cylinders)	$\frac{3}{32}$ in.	Thin brass	$\frac{3}{16}$ in.
,,	(small cylinders)	$\frac{1}{16}$ in.	Aluminium	$\frac{1}{5}$ in.

Machine Tool Repairs. This section usually comes under the control of the Works Engineer, and its organization depends largely on the type of plant in general use. The same applies to the class of labour; high-speed machine tools, such as modern automatics, etc., demand a better grade of worker than the heavier type of engineering.

The section should be as near as possible to the machine shops, and should be equipped with modern machines and tools, capable of dealing with all repairs in a quick and efficient manner. As far as practicable, replaceable parts for repair work should be made in the departments. This provides work for slack periods (between actual repairs), and more often than not such parts can be made more cheaply than if purchased outside. Special-purpose machines can also be economically built in this department if modern equipment is provided.

Each machine section or department, where the number of machines warrant it, should have one or more fitters, in proportion to its size, to carry out adjustments and running repairs. If one of these fitters is permanently attached to the machine department, it will ensure that the machines are properly looked after. If he is not satisfied with the tool-setters' or operators' treatment of any particular machine, he reports to his foreman, who in turn will confer with the Machine Tool Inspector. It is a good idea to combine the duties of Machine Tool Inspector with those of the Safety Officer, as this ensures that both machine guards and machines are under constant supervision as regards safety.

In the case of a breakdown, the fitter should report immediately to his foreman, who will decide what is necessary to effect a satisfactory repair with as little delay as possible. Complete overhauls should be periodically carried out, especially on machines required

for accurate work. The machine should be completely dismantled, all parts washed and examined, and an estimate should then be submitted to the Works Engineer, who will have full details of the history and previous repairs to the machine in question on the Plant Card (Fig. 6, Chapter I). He will decide how much may be expended on the repairs, or whether it would be more economical to buy a new machine. A comparison between the production times of the old and the new machines will, of course, be taken into consideration.

The method of placing the Repairs Order, the booking of materials, labour, etc., is the same for all departments (see Chapter I). It may be mentioned that stock cards are kept for all spare parts for replacements, each part being booked out to the appropriate machine.

When new machines are installed, the foreman satisfies himself that they are properly lubricated and generally inspected before they are handed over to the machine shop section or to the tool-setter. The lubrication of high-class machines is very important, and it is essential to ensure that every moving part has been properly lubricated before the machine is put into commission.

The foreman should be supplied with all the necessary checking instruments, such as revolution counter, clocks, etc. A rotoscope is a most useful item of testing equipment, a very handy type being the "Ashdown." It is portable and requires no electric leads, having a clockwork movement. Not only can high speed itself be measured but it is possible to see the job appearing to stand still, though it is actually running at high speed. This device is especially useful in testing new machines installed by the department.

CHAPTER VI

FANS AND THEIR APPLICATION

FANS are used in industry to such an extent that it is impossible to deal with every class of application. A brief explanation under main headings may, however, provide a general survey.

AIR

Air is a mixture of various gases, chiefly oxygen and nitrogen; their proportionate volumes, in the case of *dry air* being about 21 per cent and 79 per cent respectively. The moisture content in *pure dry air* may be anything up to 4 per cent. The weight of air varies according to its temperature, moisture content, and barometric pressure; and its weight may be calculated from the Willis Carriers formula—

Weight per Cubic Foot.

$$\text{Moist Air, } W = \frac{0{\cdot}0028862b - 0{\cdot}001088e}{1 + 0{\cdot}0021758t}$$

$$\text{Dry Air, } W = \frac{0{\cdot}0028862b}{1 + 0{\cdot}0021758t}$$

For all practical purposes the following simplified formula can be used.

$$W = 1{\cdot}325b_1/T$$

where W = weight in lb. per ft.^{3}
t = temperature in $^\circ$ F.
b = barometric pressure corrected in respect to altitude.
b_1 = barometric pressure in inches of mercury.
e = pressure due to vapour in the air in inches of mercury.
T = absolute temperature in $^\circ$ F., i.e. observed thermometer reading + 459·2°.

Relative Humidity is the ratio of the weight of water vapour in a given space to the weight which the same space is capable of containing when fully saturated at a given temperature. Readings of the relative humidity can be checked with a hygrometer, comprising a wet- and dry-bulb thermometer and a set of tables, as in Table XIV.

The instrument comprises two thermometers attached to a stand carrying the graduated scales. The bulb of one is exposed to the air; whilst the other is kept wet by means of a cloth wrapped round it and having its lower end immersed in a small vessel containing water. If the atmosphere is dry, there will be rapid evaporation

TABLE XIV

Relative Humidity Table (Per Cent Saturation)

Arranged from Glaisher's Tables

Dry Bulb Temp. ° F.	Difference between Wet and Dry Bulb in ° F.																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
30	83	69	60																					
35	90	80	72																					
40	92	84	76	69	63	57	51	46	42	38	34	31												
45	92	85	78	72	66	60	55	50	46	42	38	34	31	28										
50	93	86	80	74	68	63	58	53	49	45	41	37	34	31	29	27								
55	93	87	81	75	70	65	60	56	52	48	44	41	38	35	32	29	27							
60	94	88	82	76	71	66	62	58	54	50	46	43	40	37	34	31	30	28	26					
65	94	88	83	78	73	68	63	59	55	51	48	45	42	39	36	34	32	29	27	25	23			
70	94	88	83	78	73	69	65	61	57	53	50	47	44	41	38	36	34	31	29	27	25			
75	94	89	84	79	74	70	66	62	58	55	52	49	46	43	40	38	36	33	31	29	27	25		
80	95	90	85	80	75	71	67	63	59	56	53	50	47	44	41	39	37	35	33	31	29	27	25	
85	95	90	85	80	76	72	68	64	61	58	55	52	49	46	43	40	38	36	34	32	30	28	27	
90	95	90	85	81	77	73	69	65	62	59	56	53	50	47	44	42	40	38	36	34	32	30	28	
95	95	91	86	82	78	74	70	66	63	60	57	54	51	48	45	43	41	39	37	35	33	31	30	
100	95	90	86	82	78	74	71	68	64	61	58	55	52	49	47	45	43	40	38	36	34	32	30	29

from the wet bulb, and its temperature will be comparatively low. But if the atmosphere is moist, the temperatures given by the two thermometers will be more nearly equal. The humidity of the air can thus be related to the difference in readings between the wet- and dry-bulb thermometers, and is obtained from the table.

These hygrometers may be of the recording type, but for more accurate readings the whirling hygrometer should be used. Messrs. Negretti & Zambra make suitable hygrometers of both types.

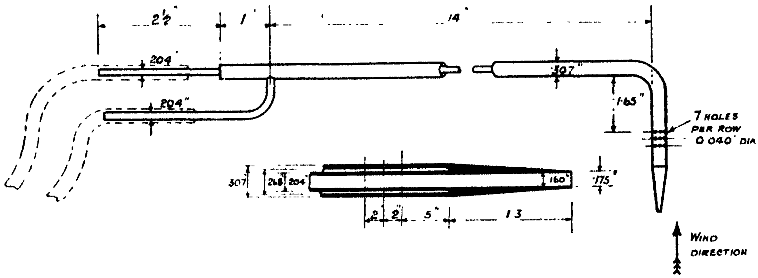


Fig. 133. Pitot Tube Suitable for Commercial Use

Volume. The volume of air which can be carried by a pipe of given cross-section varies directly with the velocity of the air in the pipe, according to the general formula

$$Q = AV^2$$

where Q is the quantity of air dealt with, in (say) ft.^{3} per sec.
A is the cross-sectional area of the pipe, in ft.^{2}; and
V is the velocity in ft. per sec.

The quantity V may be measured by a Pitot tube (as described below). Great care must be taken to keep the units consistent (i.e. to deal consistently in feet or inches, minutes or seconds, etc.). The general formula for velocity is discussed on page 221.

Velocity. The velocity of air is usually measured in feet per minute, and can be arrived at by the use of a *Pitot tube*; for velocities, say, up to 3 000 ft. per min., the anemometer may be used.

The Pitot Tube. The Pitot tube is arranged so that the fluid or gas whose velocity is to be measured enters the inner tube directly. The small drilled holes in the outer portion are thus normal to the flow. The inner and outer tubes are connected to the two legs of a U-tube or comparable measuring device. The pressure in the inner tube is the total pressure, whilst that in the outer tube is the static pressure. The difference in level between the two legs of the U-tube is a measure of the velocity pressure.

The Pitot tube is an accurate instrument, but its disadvantage

is the trouble it entails in making the openings in the pipes and ducts for its insertion. The average velocity across a pipe is found by taking a series of readings, moving the centre line of the orifice across the section of the pipe, from the centre line to the outside, and then dividing the sum of all the velocities measured by the number of readings taken. Care should be taken to keep well away from bends, elbows, etc., when drilling the hole for inserting the instrument.

A drawing of a modification of the standard Pitot tube adopted by the National Physical Laboratory is shown in Fig. 133, the only difference being that the pipe is bent with a gradual bend, whereas the National Physical Laboratory standard has a sharp right-angled elbow. The sharp angle is difficult to manufacture and for ordinary commercial work a radius will not affect the accuracy to any great extent. The National Physical Laboratory will, if necessary, check a Pitot tube for a small fee, giving a correction factor for use with the instrument.

WATER GAUGES. The reading of all water gauges is obtained from the difference in the level of the water in the two legs.

Against each leg of the U-tube, a scale is fixed, graduated so that zero reading is at the centre; the divisions are numbered according to their distance from this centre. The two zero marks are set in line. A quantity of water is then introduced into the U-tube such that when no pressure is acting, the water is level at zero on each scale. Great care must be taken to see that no air bubbles remain in the water. In some cases paraffin is used instead of water; this obviates the possibility of bubbles. To allow for the difference in specific gravity between paraffin and water, the readings should be divided by 0·8, which is the specific gravity of paraffin.

For greater accuracy, an inclinable water gauge will give more exact readings. Fig. 134 shows one made by the author.

In order to allow direct readings to be taken—always provided that the scales are set to read zero when the gauge is not connected—the scales on each leg of the tube are so divided that their graduations represent twice their real value; e.g. $\frac{1}{8}$ in. on the scale corresponds to $\frac{1}{4}$ in. on the gauge.

By adjusting the slope of the gauge, the length on the scale corresponding to any gauge reading can be increased to, say, 2, 4, 6, 8, or 10 times. Thus, in the last instance, $\frac{1}{2}$ in. water gauge would represent a distance of 5 in. along the scale.

For very high velocities, or for checking the static pressure, it may be necessary to use mercury instead of water; in this case correction will be necessary. It must be remembered that

$$1 \text{ in. of mercury} = 13{\cdot}6 \text{ in. water gauge.}$$

$$\therefore \text{ (inches of mercury)} \times 13{\cdot}6 = \text{reading in inches water gauge.}$$

When taking the velocity, a number of readings should be made,

starting at the centre of the pipe or duct, and working to the side, say inch by inch. Care must be taken to see that the nozzle is parallel with the stream, pointing towards the flow. The test hole

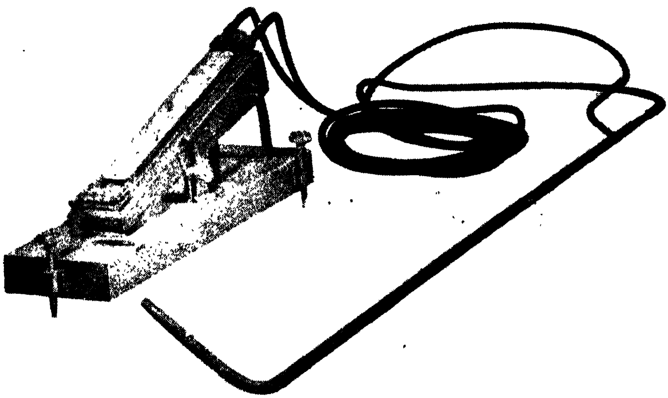


FIG. 134. PITOT TUBE AND INCLINABLE WATER GAUGE (G.E.C.)

should always be drilled in a parallel pipe as far from bends as possible; and the holes in the Pitot tube should be kept clear. If these simple precautions are taken, the readings can be relied

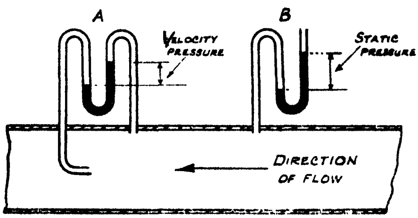


FIG. 135. METHOD OF TAKING AIR MEASUREMENTS

on. In Fig. 135, *A* shows the method of taking the velocity pressure or head of difference, and *B* the static pressure.

The loss in head of a fluid in a pipe due to friction against the walls varies as the square of the velocity. Due allowance must therefore be made for this loss. Charts have been prepared to enable the loss to be read off for various pipe sizes, with various velocities or rates of flow.

Great waste results from using too high a velocity. If the velocity is doubled, the pressure and friction loss is quadrupled, whilst the power required (which varies with the cube of the velocity) has to be increased eight times. Thus, to deliver twice as much air, eight times as much power is required by the blower, for a given size of pipe.

The use of the Pitot tube (Fig. 134) for measuring velocities of gases is based on the fundamental formula $V = \sqrt{(2gh)}$, where V = velocity of flow in feet per second; g = the acceleration due to gravity (32·2 ft. per sec. per sec.); and h = the pressure head, or difference of pressure. Taking, for example, a tank of water, and piercing a hole 10 ft. below the surface level of the water, the velocity of flow in feet per minute would be—

$$V = \sqrt{(2gh)} = \sqrt{(2 \times 32{\cdot}2 \times 10)} = 25{\cdot}37 \text{ ft. per sec.}$$

$$\therefore \text{ Velocity in ft. per min.} = 25{\cdot}37 \times 60 = 1\,522{\cdot}2$$

The head h is usually taken with a water gauge and is measured in inches. We have, therefore, to divide the equation by 12; allowance must also be made for the density of air, compared with that of the water; taking the weight of water as 62·418 lb. per ft.^{3}, the formula, therefore, becomes—

$$V_m = \sqrt{\left[\frac{2gh}{12} \times \frac{62{\cdot}418}{k} \times 60\right]}$$

where k = weight per ft.^{3} of air; and

V_m = velocity in ft. per min.

The value of k varies with the temperature of the air and can be taken from Table XV, which also gives the volume of 1 lb. of air in ft.^{3}.

The constant k is included because air at constant pressure changes its volume in proportion to its temperature, the necessary constant is derived from the formula at the top of Table XV, p. 222, which gives the volume and weight of air at different temperatures and atmospheric pressure.

By referring to the table, it will be noted that 1 lb. of air at 60° F. has a volume of 13·1 ft.^{3}, whereas the volume of 1 lb. of air at 140° F. is 15·11 ft.^{3}, an increase of 2·01 ft.^{3}.

The static pressure in a pipe line may be measured by using the connection to the side holes of the Pitot tube only, directly connecting to one leg of the U-tube water gauge, the end of the other leg being open to atmosphere.

Volume

TABLE XV

VOLUME AND WEIGHT OF AIR AT DIFFERENT TEMPERATURES AT ATMOSPHERIC PRESSURE (29·92 IN. MERCURY)

Formulae :—

$$\text{Weight in lb. per ft.}^3 = \frac{1{\cdot}325 \times \text{barometric pressure in inches}}{\text{Absolute temperature, °F. (= observed temperature, °F. + 459·2)}}$$

$$\text{Volume of 1 lb. air in ft.}^3 = \frac{53{\cdot}3 \times \text{absolute temperature, °F. (= observed temperature, °F. + 459·2)}}{\text{Atmospheric pressure (14·7 lb./in.}^2) \times 144}$$

Temp. °F.	Vol. of 1 lb. Air Ft.³	Wt. per Ft.³ Lb.	Temp. °F.	Vol. of 1 lb. Air Ft.³	Wt. per Ft.³ Lb.	Temp. °F.	Vol. of 1 lb. Air Ft.³	Wt. per Ft.³ Lb.
0	11·57	0·0864	150	15·36	0·0651	350	20·41	0·0490
10	11·81	·0847	160	15·62	·0640	375	20·96	·0477
20	12·06	·0827	170	15·87	·0630	400	21·69	·0461
30	12·32	·0810	180	16·12	·0620	450	22·94	·0436
32	12·39	·0807	190	16·37	·0611	500	24·21	·0413
40	12·59	·0794	200	16·62	·0601	600	26·60	·0376
50	12·84	·0778	210	16·88	·0592	700	29·59	·0338
60	13·10	·0764	212	16·93	·0591	800	31·75	·0315
70	13·35	·0749	220	17·13	·0584	900	34·25	·0292
80	13·60	·0735	230	17·39	·0575	1 000	37·31	·0268
90	13·85	·0722	240	17·63	·0567	1 200	41·84	·0239
100	14·10	·0709	250	17·89	·0559	1 400	46·95	·0213
110	14·36	·0696	260	18·14	·0551	1 600	52·08	·0192
120	14·61	·0684	275	18·52	·0540	1 800	57·14	·0175
130	14·86	·0672	300	19·16	·0522	2 000	62·11	·0161
140	15·11	·0661	325	19·76	·0506	3 000	87·72	·0114

FANS

When selecting the best type of fan for a particular purpose, there are many points to be considered. Centrifugal fans can be divided roughly into two types: those having runners with straight radial blades, and runners with curved blades. The characteristics of the latter vary greatly, depending on whether the blades are curved backwards or forwards with respect to the rotation. In all centrifugal fans there are two independent and separate sources of pressure, the centrifugal force due to rotation of the column of air, and the kinetic energy due to its velocity on leaving the periphery of the fan runner. The graphs in Fig. 136 show the characteristics for three types, *paddle*, *multivane*, and *blowing* fans; the figure also shows the different types of runners.

Paddle Type Fan. This is perhaps the earliest type of fan, and whilst it is less efficient than the multivane, it still commands a wide field of application, e.g. in connection with dust exhausting, such as sawdust from woodworking machines, dust from buffing machines, etc.

The runner is usually composed of six or eight radial blades, a six-bladed type being illustrated in the upper part of Fig. 136. From this will be apparent the strong construction which enables it to withstand the shocks to which it may be subjected when used for a heavy class of work. The clearance between the blades ensures that the fan will not become clogged with fluff or larger material that may be carried through to it.

With the straight-bladed runner, the pressure drops off rapidly under overload, but increases when the fan is run at less than its rated capacity; therefore, when it is required to throttle the supply from the fan without increasing the pressure, thus keeping a uniform pressure with a varying resistance, the straight-bladed type is best. Where noise must be reduced to a minimum, it is not advisable to fit the straight-bladed fan for working against a high pressure, as a high-frequency note is obtained, due to the change of direction of the air on entering the fan inlet. A blowing fan should be used in such cases.

A paddle type fan having commendable features, and for which high efficiencies are claimed, is the "Adra" fan, which has a special intake distributor, the ends of which are curved for the purpose of diverting the flow of gases in order that the impact of dust particles in the gas stream shall be spread over the whole area of the fan blade, instead of the dust impinging on one portion of the blade only.

The Multivane or Curved-bladed Fan. With this type of fan the static pressure is greatest at normal load; it decreases at capacities either above or below normal load, and for this reason it is possible to decrease the load without an appreciable increase in the pressure and without reducing the speed of the fan. On this account, such fans have a very wide field of usefulness over an unusually extended pressure range, over which their high efficiency is well maintained. They are used for general ventilation or for handling dust of a light non-clogging type. Among its applications are plenum systems, induced and forced draught, mine and ship ventilation, etc. These fans are known as a "clean air" type and should not be used where there is a tendency for the vanes to become clogged with fluff or dust. The reason will be readily understood by referring to the Keith & Blackman runner shown in Fig. 136.

Blowing and Exhausting Fans. For high water-gauge pressures, or where adaptability of control to suit variations in pressures at fixed speeds is required, fans of this type are best. There is a complete absence of surging, and they are extremely quiet in operation. Their efficiency is as high as 80 per cent.

Propeller Fans. As, later in this chapter, reference is made to ventilation, it would not be complete without mention of the propeller fan. This may be of the box-blade or propeller-blade type, the latter usually giving slightly greater efficiency. It is usual for these fans to be direct-driven by motors, the blades being

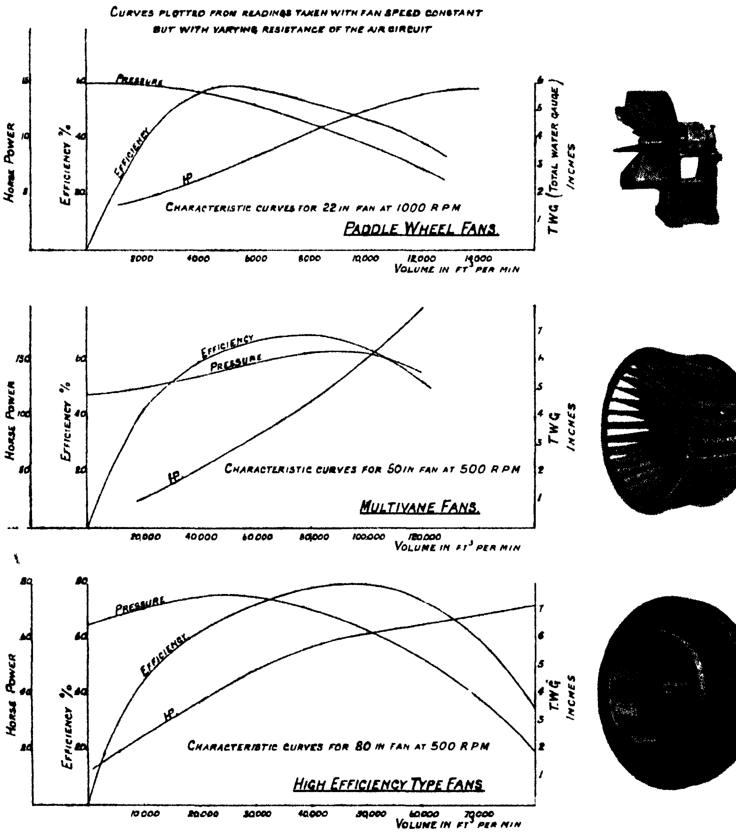


FIG. 136. DIFFERENT TYPES OF FANS AND THEIR CHARACTERISTICS

mounted on the motor spindle. It is surprising that very little has been done in the way of streamlining the motor. The author knew of only one firm in this country which has put forward a streamline fan, namely, the Aeroto Company,* which claims very high efficiencies for this type. A characteristic difference between

* Aeroto fans are now manufactured by Messrs. Davidson & Co., Ltd., Sirocco Engineering Works, Belfast.

propeller fans and centrifugal blowers is that, for a propeller fan, increased resistance to the movement of the air leads to a reduction in the volume of air dealt with and an increase in power consumption. For a centrifugal blower, however, increased air resistance means a reduction in the volume dealt with, but a reduction *also* in the power consumed.

The graphs in Fig. 136 and much of the information on fans are included by kind permission of Messrs. Keith & Blackman, Ltd.

Fan Characteristics. All fans are based on the fundamental consideration that the fan efficiency remains constant; therefore, when one or more conditions are varied, the rest must vary accordingly. The following are a few of the most useful fan laws.

For a given fan size.

When speed varies—

(1) Capacity varies directly as the speed ratio.
(2) Pressure varies as the square of the speed ratio.
(3) Horse-power varies as the cube of the speed ratio.

When pressure varies—

(4) Capacity and speed vary as the square root of the pressure.
(5) Horse-power varies as $(\text{pressure})^{3/2}$.

For a constant pressure and point of rating.

When fan size varies—

(6) Capacity and horse-power vary as the square of the fan size.
(7) Speed varies inversely as the fan size.

The above may be combined for one convenient operation.

When fan size and speed both vary—

(8) Capacity varies as the ratio, $(\text{size})^3 \times$ (ratio of speed in r.p.m.).
(9) Pressure varies as the ratio, $(\text{size})^2 \times$ (ratio of speed in r.p.m.)^2
(10) Horse-power varies as the ratio, $(\text{size})^5 \times$ (ratio of speed in r.p.m.)^3 or horse-power varies as the ratio of (capacity $\times$ pressure).

For constant pressure.

When density varies—

(11) Speed, capacity, and horse-power vary inversely as the square root of the density, that is, inversely as the square root of the barometric pressure and directly as the square root of the absolute temperature.

For constant capacity and speed.

When density of air varies—

(12) Horse-power and pressure vary directly as the air density, that is, directly as the barometric pressure and inversely as the absolute temperature.

For constant amount by weight.

When density of air varies—

(13) Capacity, speed, and pressure vary inversely as the density, that is, inversely as the barometric pressure and directly as the absolute temperature.

(14) Horse-power varies inversely as the square of the density, that is, inversely as the square of the barometric pressure and directly as the square of the absolute temperature.

When both temperature and pressure vary—

(15) Capacity and speed vary as pressure $\times$ absolute temperature. Horse-power varies as $(\text{pressure})^3 \times$ absolute temperature.

The work done to keep a column of air 1 ft.^{2} in cross-section moving at a rate of 1 ft. per min. against a pressure equivalent to 1 in. water gauge (= 5·19 lb. per ft.^{2}) is, neglecting weight of air and friction, 5·19 ft.-lb. per min. In terms of horse-power this is equivalent to

$$5{\cdot}19/33\,000 = 0{\cdot}000157 \text{ h.p.}$$

For a given capacity, pressure, and horse-power, a fan will operate at a definite efficiency; therefore we have—

Total efficiency

$$= 0{\cdot}000157 \times C \times \text{total pressure in inches water gauge;}$$

Static efficiency

$$= 0{\cdot}000157 \times C \times \text{static pressure in inches water gauge,}$$

and the horse-power required to drive the fan under given conditions of volume of flow and pressure head to be overcome will be

$$\frac{C \times L \times 5{\cdot}19 \times 100}{33\,000 \times \text{efficiency of fan}}$$

where C = volume of air or gas in ft.^{3} per min.,; and

L = pressure head against which column of air is moved, in inches water gauge.

The efficiency of fans varies from 69 per cent to 75 per cent.

Anemometers. For low velocities, such as that in the suction from buffing spindle cowls, the checking of air velocities of plenum heating systems, etc., the anemometer is a useful instrument. It comprises a small fan delicately balanced and geared to a clock dial counter which records the velocity in feet per minute. This is de-clutched by a small lever, readings usually being taken over one minute. Messrs. Short & Mason make a handy instrument of this type. When the speed is required in miles per hour, the velocity in feet per minute must be divided by 88.

To find the pressure in pounds per square foot, the square of the velocity in feet per second must be multiplied by 0·0023.

AIR DUCTS AND TRUNKING

Air ducts or trunking should be of ample proportions throughout their whole length. If the resistance is constant the following laws must not be forgotten—

(1) Pressure varies as the square of the speed; and
(2) Horse-power varies as the cube of the speed.

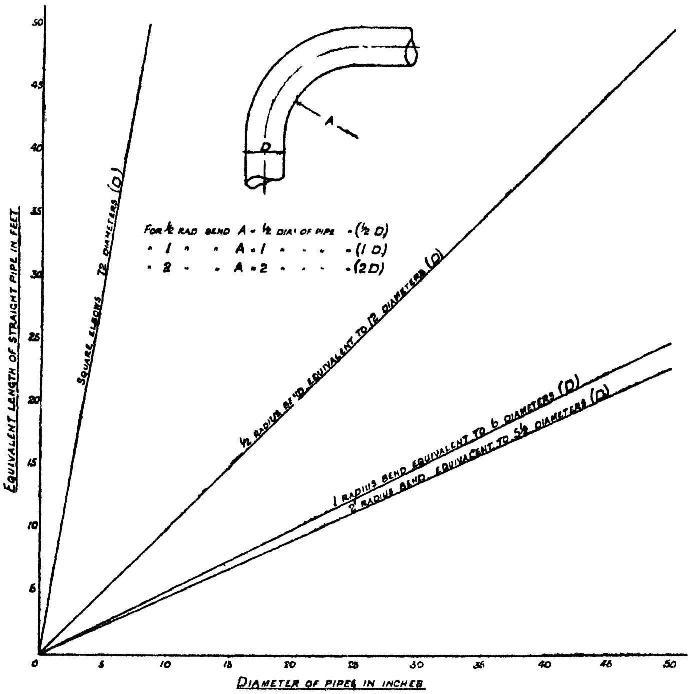


FIG. 137. LOSSES DUE TO BENDS

It will be clear that the power absorbed by a pressure fan increases very rapidly with increase of speed; slow-running fans and large air ducts are, therefore, much more economical than fast-running fans and small ducts. A pressure of 2 in. water gauge should prove suitable on most "blowing" jobs, and to arrive at the minimum diameter of trunking a good rule is to make the area of the main trunking equal to the sum of the areas of the branch pipes; thus the duct will become larger at the fan end, and a fan should be selected with an inlet equal to or larger than this area. In any

trunking system, even when well designed, the losses due to eddies, where the direction of flow is altered, are considerable; all bends should therefore be as gradual as possible, and in no case should they be less than one and a half times the diameter of the pipe. Losses due to bends are indicated in Fig. 137. It must be emphasized that, at the entry to an air duct, not all the area of the entrance is effective, owing to the formation of eddies and to conflicting currents of air at that point. The amount of this loss varies with the shape and roughness of the sheeting forming the entrance. A tapering hood should be used where possible as an entry to a branch pipe, in which case the average loss in static pressure may be about 5 per cent. A taper of 1 in 5 for such hoods is recommended.

It is particularly bad practice to arrange two branches directly opposite each other on a main suction pipe, especially if one branch is large and the other small, as the movement of air from the larger pipe will tend to prevent the proper working of the smaller. In any case, whatever the relative sizes, mutual interference will be caused. Branches should not be made to enter the main pipe on the underside, owing to the possibility of small pieces of foreign matter, which may be travelling along the main, falling into them. The angle to the general direction of flow at which branches enter the main pipe is also very important. For example, a 45° branch is much better than one at right-angles, as it enables velocity pressure as well as static pressure to be utilized, and has less tendency to produce eddies with consequent loss.

APPLICATION OF FANS

Ventilation. The Factory and Workshops Act requires that in every workroom or workshop in a factory, sufficient means of ventilation must be provided and sufficient ventilation maintained; under the same Act a reasonable temperature must also be maintained. Apart from the Act, if working conditions are comfortable, production will be greater. It is very difficult to achieve good ventilation without draughts. If a man is exposed to a wind of 10 m.p.h. velocity, it will bring him more than 300 000 ft.^{3} of air in one hour. Such ventilation could not, however, be tolerated in a workshop, 3 000 ft.^{3} per hr. being a maximum. An average adult on light work will breathe about 0·25 ft.^{3} of air and exhale 0·01 ft.^{3} of CO_2 per min. Moreover, about 5 per cent of the oxygen in a breath of air is used in the body. Ordinary outside air usually contains about four parts of CO_2 in 10 000, and good ventilation in a workshop should not yield more than 6 to 8 parts per 10 000. It is usual, for workshops, to allow three air changes per hour, i.e. a 20-minute air change.

Forced Ventilation may be one of three main types—

(1) *Plenum*, in which air is forced into a building by a fan which distributes it through a system of trunking, with openings at

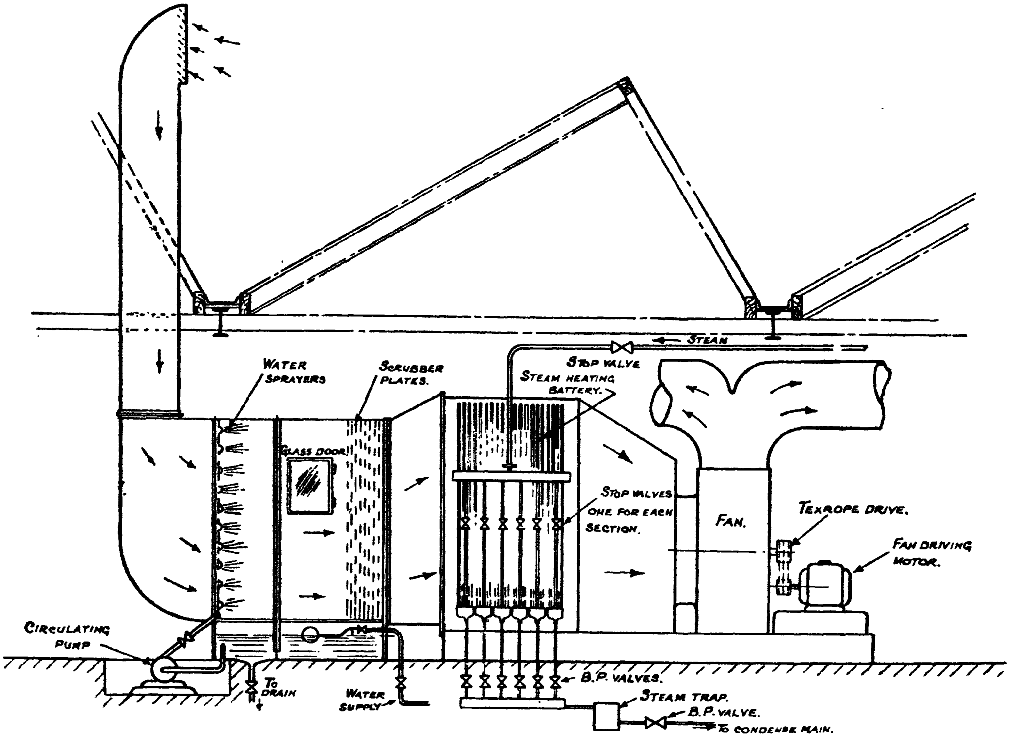


FIG. 138. PLENUM HEATER, FAN, AND WASHER

suitable points; the air finding its way out by existing outlets, e.g. doors, opening lights, windows, etc.

(2) *Exhaust*, depending on the extraction of air by propeller type fans, the air being drawn in through suitable inlets.

(3) *Combined Plenum and Exhaust Systems*, such as might be used for shops where buffing or paint spraying is carried out, in conjunction with a plenum heating system.

Plenum System. Whilst the best form of ventilation is by natural ventilation, i.e. by windows and suitable outlets in the roof, this is

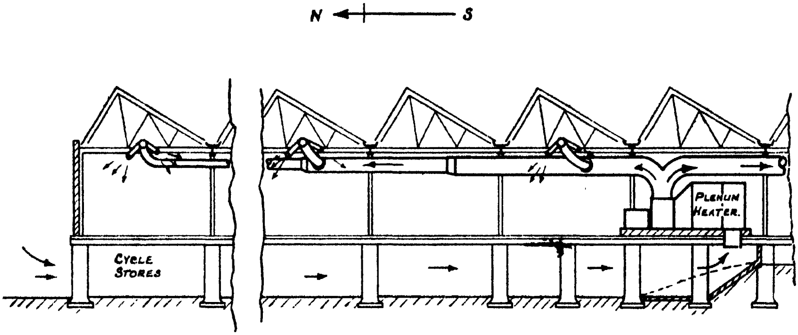


FIG. 139. SECTION OF PLENUM HEATING SYSTEM DRAWING AIR FROM COOL SIDE OF BUILDING VIA CELLAR, WHICH MAY BE USED FOR CYCLE STORAGE

not always possible, owing to the size of present-day buildings. For a large factory with a north-light roof the plenum system is the best. Apparatus for heating and washing the air can be combined with the fan, so that the system can be used for clean, dry, cool, or hot air according to requirements. Fig. 138, which is self-explanatory, shows a fan, heater, and washing unit complete. The air velocity in this system should be reduced when the air is passing the heating elements, and raised again when it has completed its journey past them. This allows time for the air to absorb the necessary quantity of heat from the elements. A bypass can be arranged in order that cold and heated air may be mixed in any desired proportions. In place of the air washer, a "Ventex" or "Visco" filter can be used; this contains a series of baffles, coated with a suitable liquid to which dust will adhere. The baffles can be dropped out in small sections and cleaned; or they may be of the fixed type, in which the liquid is pumped to the top, from whence it flows down the baffles, the dust being washed into a sump; or a rotary type, in which the filter baskets are dropped, one by one, into the cleaning liquid.

When a plenum system is being laid out, provided the air is fairly clean, the intake should be placed on the north side, as this

makes a few degrees difference to the temperature in hot weather. If there are cellars, advantage should, if possible, be taken of them, in order to arrange the fan and heater more centrally. Fans of the multivane type should be used, as it is then possible to shut off one part without considerably increasing the output from the rest of the system. The outlet ducts should be arranged so that the workpeople are not in a draught; the velocity at outlet should not be greater than 250 ft. per min., otherwise it will be uncomfortable.

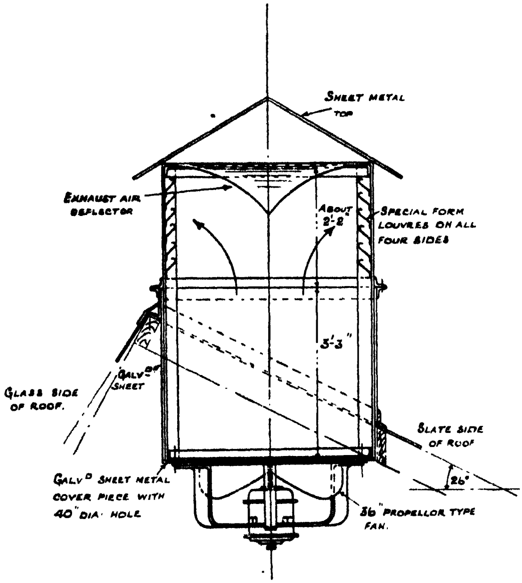


FIG. 140. EXHAUSTING FAN AND OUTLET FOR NORTH-LIGHT TYPE ROOF

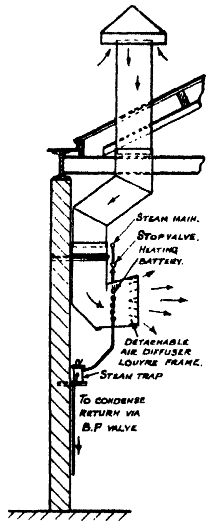


FIG. 141. SUCTION TYPE VENTILATOR

A well laid out scheme is shown in Fig. 139, in which advantage is taken of the geographical position of the factory.

Exhaust Systems. Where buildings are smaller, suitable exhausting propeller fans can be arranged in the roof, in conjunction with windows or suitable inlets near to floor level. If these inlets are made like a Tobin tube, heaters can be arranged in them to heat the room concerned. Where there are several windows this is not practicable, and some other means of heating are necessary. Fig. 140 shows an exhaust fan and outlet built by the author for a north-light roof; the fan exhausts 15 000 ft.^{3} of air per min.; Fig. 141 illustrates a successful air inlet used in a room situated in the centre of a works where air is being exhausted from spraying booths and

extra ventilation is necessary, owing to the nature of other work in the department. The air heater will be noted. As in the plenum system, care should be taken to reduce draught to a minimum.

Artificial Draught for Boilers

Fans can be used for artificial draught for coal-fired boilers in three ways—

(1) *Forced* draught, in which air is supplied to the furnace via the ash pit;

(2) *Induced* draught, which draws off the hot gases after combustion; and

(3) Combined induced and forced draught.

Forced Draught. On small plants, this is usually effected by steam jets and injectors arranged in the furnace bars; but larger plants usually have a fan delivering air to the underside of the grate, care being taken to see that the stack is large enough to create a suction over the whole of the boiler setting. If this suction is not maintained, trouble will be experienced due to overheating of the brickwork as a result of the hot gases not being removed sufficiently quickly. The suction over the fire should never be less than 0·03 in. water gauge. The installation of a forced draught system will often enable the rating of a boiler to be considerably increased above that for the ordinary type without forced draught. It will also enable lower and cheaper grades of fuel to be efficiently burned.

Forced draught fans should show a good efficiency over a wide speed range. The delivery pressure curve should rise steadily from free delivery to zero delivery. Bearings must be of ample area and robust construction, and preferably water-cooled.

A forced draught fan can be made much smaller than an induced draught fan to be used under comparable conditions, as, owing to the expansion of the burnt gases under heat, the volume to be dealt with by the induced draught fan is greatly increased. Both the forward-bladed and paddle type fans are low in efficiency and speed for forced draught; and, as they have no reserve pressure, fans of the back-curved type are generally used in their place.

Induced Draught. The fans are usually arranged at the base of the stack. They should not be so powerful as to create an excessive suction through the fuel bed, as this only tends to cause leaks through the brickwork and inspection doors, which allows excess cold air to filter in and so reduce the efficiency of combustion. The amount of air required will depend on the type of coal. It is usual in theory to allow 12 lb. of air per pound of fuel for an average grade of bituminous coal; but this figure is rather high, as only 7–11 lb. of air are required for the complete combustion of 1 lb. of coal; most fan makers advise an allowance to be made for 100 per cent excess air with hand-fired boilers and about 50 per

cent with boilers fired by mechanical stokers. Like forced draught fans, a steady rise in the pressure delivery curve to zero delivery should be obtainable. The advantage of this is felt when several installations deliver into a common uptake; one fan will not

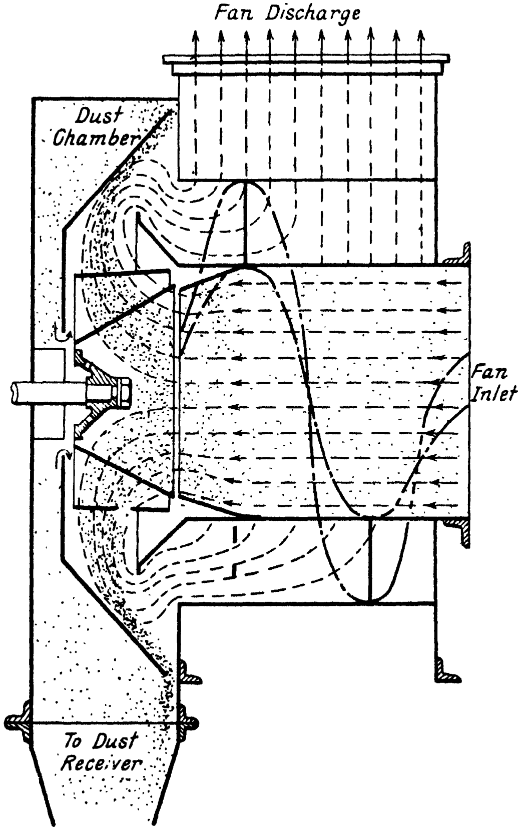


FIG. 142. DIAGRAMMATIC VIEW SHOWING PRINCIPLE OF OPERATION OF KEITH BLACKMAN GRIT ARRESTER

adversely influence another if the delivery pressure characteristics of all fans are suitable, as the fans will then share the load between themselves.

Special care is necessary in the selection of the material for the vanes of induced draught fans. The temperature of the gases will be between 300° and 600° F. and the vanes must withstand this heat without deterioration. Water-cooled bearings of generous dimensions should be provided.

The fans are sometimes arranged to serve a double purpose, namely, induced draught and grit arresting, an arrangement which the author has used with success for some years. The fan employed is the Keith Blackman grit arrester fan shown in Fig. 142. A special two-stage housing is adopted, the first having a conical vortex chamber in which the dust is thrown out centrifugally and diverted into the dust collector. The cleaned gases pass on to the second stage of the housing, which has a spiral diffuser converting the velocity energy of the rotating gas stream into useful pressure; the diagram is self-explanatory.

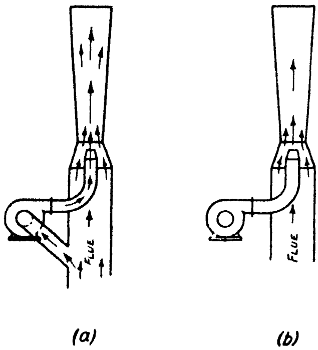


Fig. 143. Venturi Stack
(*a*) Inner circuit. (*b*) Outer circuit

The Sturtevant "Cindervane" fan works on a somewhat similar principle; the dust in its passage along the surface of the blade is trapped in V-shaped channels arranged on the periphery of the wheel. These channels project into dust chambers formed within the fan casing and the dust is carried by the channels into the dust chamber, which forms a dead air space. The dust therefore drops into a hopper at the base of the fan.

Venturi Chimneys. In some cases, instead of building high chimneys, a "Venturi" chimney is used with a fan connected to a nozzle in the neck of the diffuser. This, of course, is a cheaper method, inasmuch as the fan or blower only has to deal with part of the gases. In some cases cool air is drawn from outside. The two schemes are shown in Fig. 143. View (*a*) shows the *inner circuit* type in which some of the gases are bypassed through the fan, and (*b*) the *outer circuit* type where air is drawn from outside.

It has been found cheaper in many cases to build several fairly small chimneys of this type rather than to discharge flues from each of several boilers into one large chimney. The frictional drag on the gases is much less, and the power absorbed in sending the gases through at a given velocity is consequently reduced.

Dust Exhaust Systems

The general use of fans and trunking for removal of sawdust, wood chips, sand, shotblast, etc., is so well known that it needs little explanation. It is essential, however, that ducts should be properly proportioned so that the required velocity can be maintained.

For woodworking machinery it is usual to allow a velocity of 2 500 ft. per min. for light shavings, 3 000 ft. per min. for sawdust,

and up to 4 000 ft. per min. for small pieces of wood, knots, etc. A typical layout was shown in Fig. 32, Chapter II (page 48).

For dust exhaust from buffing machines, sandblast, etc., velocities of from 250 to 1 000 ft. per min. are permissible, depending on the class of work. The areas of the fan inlet and main duct should be at least 20 per cent greater than the combined areas of the branch pipes. All hoods should be as close to the wheel or mop as possible, with dampers for shutting off any machines which are not in use; bends should be as gradual as possible, and reductions in sizes of trunking made by taper pieces. The fan should be of the straight-bladed type so that the velocity in the main trunking can be kept constant in order to carry the dust when some of the branches are shut off.

The clearance between blades and casing should not be so small that chips of wood, etc., can become wedged and so damage the rotor, nor should it be so large as to exert a retarding effect on the air leaving the delivery outlet. Pressures up to 20 in. water gauge are encountered in this class of work.

Grinders and buffing machines should not be connected to the same system, as there is a possibility of fire, due to the emery wheel grits igniting the fluff from the mops. It must always be remembered that a good suction is not everything; there must be sufficient openings at the end of a system to admit enough air to carry the dust away in the main trunking.

Dust Separators. The separation of dust, in some form or other, from air is required in almost every industry. The dust may arrive at the separator either from exhaust systems, such as those for buffing, grinding, sandblasting, or woodworking shops, etc., or from pneumatic conveying systems for coal or other dusts. It may be collected by means of cyclones and similar devices, bag filters, or by electrolytic precipitation.

Cyclones. The air, laden with dust, is delivered by a fan to the cyclone separator, the inlet being arranged to give a centrifugal action. This causes the dust to be deposited in a box at the bottom, the air escaping through the outlet at the top. The conical shape of the separator gradually reduces the radius of rotation of the dust particles in their journey downwards, and thus reduces the centrifugal force. Where sandblast and grinding dust need separation, excessive wear takes place; on a plant of this description, the author found it necessary to fit new liners every year. A complete lining of soft rubber was then tried; and has been in use for over four years without any appreciable wear taking place. It is difficult to give sizes for cyclones, as a light dust will require a much larger plant than would be needed to deal with heavier dust; it is best, therefore, to inform the cyclone manufacturer of the requirements. For light buffing dust, "lint" (fluff), etc., the Buffalo Forge Company recommend that the velocity of discharge would not exceed 300–480 ft. per min.

Cyclone Sizes and Volumes. Fig. 144 and Table XVI, based on information kindly supplied by Messrs. Keith & Blackman, give typical figures for sizes and approximate volumes.

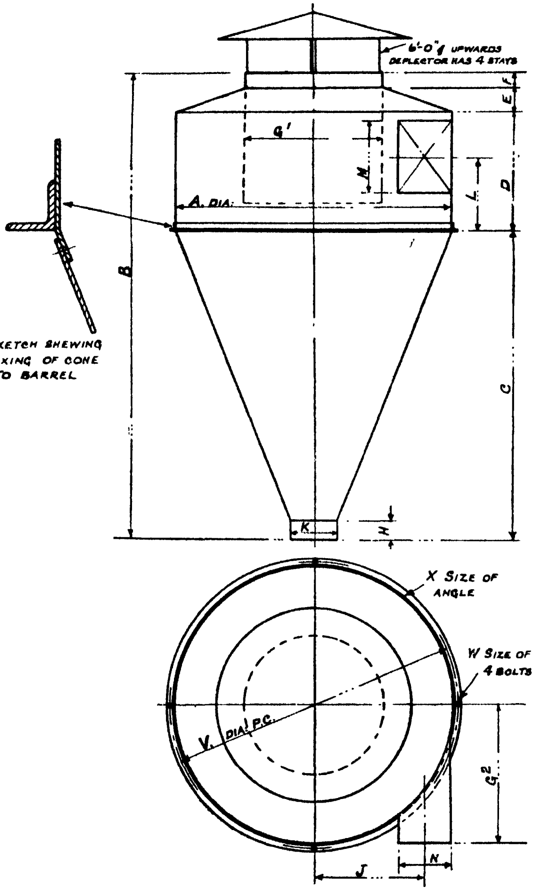


Fig. 144. Keith & Blackman Centrifugal Dust Settlers

It is of fundamental importance that the pipe leading to the cyclone should be tangential to the body, otherwise serious disturbance will be set up in the dust already within the apparatus. There is considerable advantage in feeding the dust in at the *outside* of the rotating mass in the body of the cyclone, as in this way deposition of the dust particles is facilitated. A second point of importance is that if the inlet to the cyclone body is of a tall,

TABLE XVI

Keith & Blackman Centrifugal Dust Settlers

*Dimensions and Approximate Volumes

A	B	C	D	E	F	G¹ & G²	H	J	K	L	M	N	V	W	X	Gauge	Approx. Volumes Ft.³ per Min.
3 0	5 0	3 3	1 3	3	3	1 6	3	1 2⅜	7	9½	9	7¼	3 1½	5/16	1¼ × 1¼ × 3/16	20	900– 1 250 max.
3 6	5 9½	3 9½	1 5½	3½	3	1 9	3	1 4¾	7½	11¼	10½	8½	3 7½	5/16	1¼ × 1¼ × 3/16	20	1 300– 1 750 ,,
4 0	6 7	4 4	1 8	4	3	2 0	3	1 7¼	8	1 1	12	9½	4 1½	5/16	1¼ × 1¼ × 3/16	20	1 800– 2 400 ,,
4 6	7 6	5 0	1 10½	4½	3	2 3	4	1 9½	9	2¼	1 1½	11	4 8⅛	⅜	1¾ × 1¾ × 3/16	20	2 450– 3 100 ,,
5 0	8 3½	5 6	2 1	5	3½	2 6	4	2 0	10	1 4	1 3	12	5 2⅛	⅜	1¾ × 1¾ × 3/16	20	3 200– 3 900 ,,
5 6	9 1½	6 1	2 3½	5½	3½	2 9	4	2 2¼	11	1 5¾	1 4½	1 1½	5 8⅛	7/16	1¾ × 1¾ × 3/16	18	4 000– 4 750 ,,
6 0	9 11½	6 8	2 6	6	3½	3 0	4	2 4¾	12	1 7	1 6	1 2½	6 2⅛	7/16	1¾ × 1¾ × 3/16	18	4 800– 5 600 ,,
6 6	10 9½	7 3	2 8½	6½	3½	3 3	4	2 7¼	13	1 9	1 7½	1 3½	6 8⅛	7/16	1¾ × 1¾ × 3/16	18	5 700– 6 700 ,,
7 0	11 6½	7 9	2 11	7	3½	3 6	5	2 9½	14	1 10½	1 9	1 5	7 2⅛	7/16	1¾ × 1¾ × 3/16	18	6 700– 8 00[illegible] ,,
7 6	12 3½	8 3	3 1½	7½	3½	3 9	5	3 0	15	2 0	1 10½	1 6	7 8⅜	½	2 × 2 × ¼	18	7 800– [illegible] ,,
8 0	13 1	8 9	3 4	8	4	4 0	5	3 2½	16	2 2	2 0	1 7	8 2⅜	½	2 × 2 × ¼	18	8 800–10 300 ,,
8 6	13 10	9 3	3 6½	8½	4	4 3	5	3 4¾	17	2 3½	2 1½	1 8½	8 8⅜	½	2 × 2 × ¼	18	10 000–12 000 ,,
9 0	14 8	9 10	3 9	9	4	4 6	5	3 7¼	18	2 5½	2 3	1 9½	9 2⅜	½	2 × 2 × ¼	18	11 500–13 500 ,,
9 6	15 5	10 4	3 11½	9½	4	4 9	5	3 9½	19	2 7½	2 4½	1 11	9 8⅝	⅝	2¼ × 2¼ × ¼	16	13 000–15 500 ,,
10 0	16 2	10 10	4 2	10	4	5 0	5	4 0	20	2 9	2 6	2 0	10 2⅝	⅝	2¼ × 2¼ × ¼	16	14 000–17 000 ,,
10 6	17 1	11 6	4 4½	10½	4	5 3	5	4 2¼	20½	2 10½	2 7½	2 1½	10 8⅝	⅝	2¼ × 2¼ × ¼	16	16 500–19 500 ,,
11 0	17 11	12 0	4 8	11	4	5 6	6	4 4¾	21	3 1½	2 9	2 2½	11 2⅝	⅝	2¼ × 2¼ × ¼	16	18 000–21 000 ,,
12 0	19 4	13 0	5 0	12	4	6 0	6	4 10	22	3 4	3 0	2 4	12 2⅝	⅝	2¼ × 2¼ × ¼	16	21 000–25 000 ,,
12 6	20 1½	13 6	5 3	12½	4	6 3	6	5 0½	23	3 5½	3 1½	2 5	12 8⅝	⅝	2¼ × 2¼ × ¼	14	24 000–28 000 ,,

* Dimensions, where not otherwise stated, in feet and inches.

rectangular shape, these effects will be secured much better than with a circular inlet, as the incoming stream can be thereby narrowed and kept well to the outside of the casing. The change

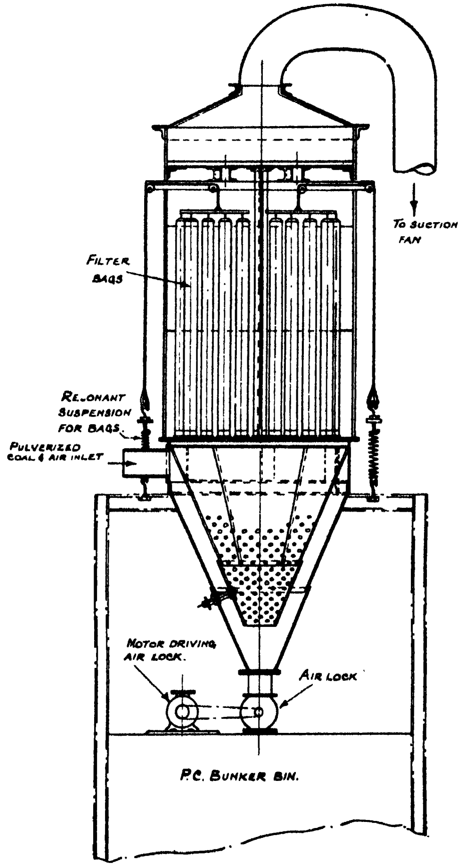


FIG. 145. WARING PATENT DUST COLLECTOR

in pipe section from the circular shape to the rectangular inlet should be gradual. The connecting piece should be horizontal on the top, with a bottom pitch of 30°–45°.

Cyclones which have to deal with dust from textile materials are often fitted with a spiral from the top of the cone to the bottom (on the principle of an internal screw thread) to guide the dust to the outlet. The dust in such cases is too light for separation to be otherwise effective, since it would continue to revolve in the conical portion for too long a period.

Whilst there are many makes of cyclones on the market, they are all designed on the same principle. For flue dust separation, the Davidson type is perhaps the best known.

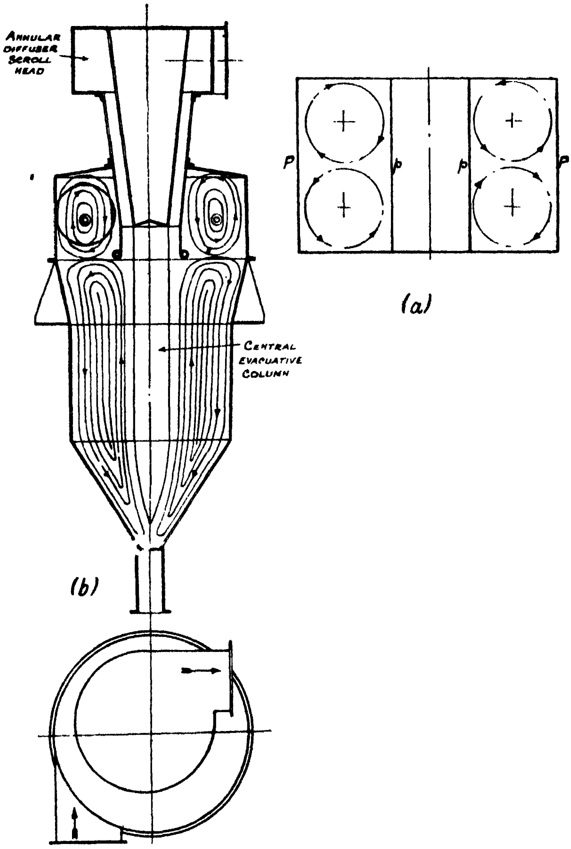


FIG. 146. CHELTNAM "MICRON" PRECIPITATOR

(*a*) Behaviour of air or gases when propelled into a cylindrical casing.
(*b*) How conditions in view (*a*) are reproduced in actual precipitator.

Where very fine dust, such as pulverized coal, has to be dealt with, combined cyclone and bag filters give good results. The author has used the Fraser & Chalmers "Waring" filter for some years with success; a diagram of this type is given in Fig. 145. The cyclone operates in the usual way, the clean air passing to atmosphere through the bags. Such systems may be either of the pressure or of the suction type, i.e. the exhauster fan may be placed either on the inlet or on the delivery side of the filters.

A new type of cyclone separator which gives remarkably high efficiencies is the Fraser & Chalmers "Micron" precipitator built to the Cheltnam patents. This type of machine (Fig. 146) owes its high efficiency to a very careful study of the behaviour of air or gases when propelled or induced into a cylindrical casing. In all such cases the centrifugal force, set up as a result of constraining the air or gases to follow the cylindrical contour, produces a pressure difference which causes the gases to split up into two eddies or vortex rings. These conditions are clearly illustrated in Fig. 146 (view (*a*)), in which the eddies in air or gas rotating in a cylindrical annulus are shown.

When the flat bottom of the annulus is removed and replaced by a conical boundary, the lower eddy or vortex extends to the bottom of the new boundary, as in Fig. 146 (view (*b*)). The vortex actually reaches the dust outlet before it returns upwards, after which part recirculates in the eddy, whilst part passes to the outlet via the central evacuative column.

The fact that this lower eddy extends to the dust outlet is the cause of the relative inefficiency of all cyclones hitherto designed. By designing the cyclone so as to avoid the withdrawal of dust from the outlet by the lower eddy, the remarkable performance of the "Micron" precipitator type has been made possible.

Fig. 147 illustrates a similar machine provided with the patent vortex control and shunting cone. This device provides an internal boundary to the lower of the two top eddies or vortex rings so that this ring brings the dust—thrown out by centrifugal force—down the inner boundary of the machine. The dust is then precipitated through the annulus between the inner boundary and shunting cone. With it is carried a small proportion of the air or gases, which is, of course, in a state of high rotation, and therefore splits up into two more vortex rings for reasons already stated. Since, however, the quantity of air in the two lower vortices is only a proportion of that entering the machine, only a small quantity of air or gases actually comes into contact with the dust passing to the dust outlet; entraining of dust is thus very largely overcome.

The machine illustrated is of the "dual" type; but for still higher efficiencies the principle of division into compartments by the patent internal cones is extended to comprise triple or even quadruple types. In dealing with silica dust, these machines pass to atmosphere practically no particles above 5 microns,* and on all dusts an efficiency of about 93–97 per cent can be obtained.

All these machines are fitted with patent outlet diffusers to reduce the total internal pressure loss, so that for a given efficiency they can be designed to operate with a lower power consumption than any other type of machine for the same purpose.

AUTOMATIC DAMPERS. When two or more pipes discharge into one

* 1 micron = 0·001 mm.

cyclone, dampers acting on the principle of non-return valves must be placed in the pipes so that, when only one of the two pipes is in operation, no air can return back along the other pipe. Dampers should be arranged so that it is impossible for material to become lodged on them or blown back against them while they are shut, otherwise difficulties will be encountered next time the pipes in which they are fixed are used. They should be located as close to the inlet as possible.

Some cyclones are fitted with automatic fire dampers. Normally these remain open. When the surrounding temperature rises above a predetermined figure a fusible plug melts, allowing the damper to close, and so preventing fire spreading by combustion of the material which is being conveyed along the pipe. Such dampers are installed in buildings where it is necessary for a pipe to pass through a fire wall, and are located on *each* side of the wall, so that should the pipe collapse from heat on one side, the fire will still not be transmitted by the pipe.

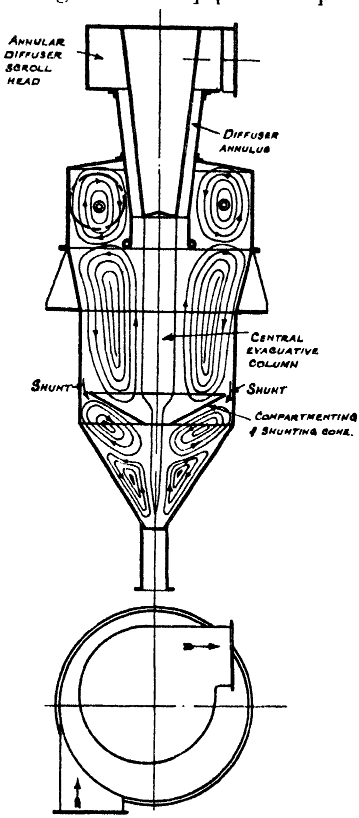


FIG. 147. CHELTNAM "MICRON" PRECIPITATOR FITTED WITH VORTEX CONTROL

Another method of dust elimination is employed in the Modave arrester, in which the gases pass through a battery of specially shaped baffles over which water is constantly flowing. The dust, after impinging on the baffles, is washed down with the water into a sump. An efficiency of 90 per cent is guaranteed.

ELECTROSTATIC PRECIPITATION is a further method of dust extraction, and is generally known as the *Lodge-Cottrell* system, due to the pioneer work done by Sir Oliver Lodge and Dr. F. G. Cottrell. In this plant a high potential is maintained between two electrodes, with the result that a corona discharge takes place, and the dust-laden gas which separates the electrodes becomes ionized. The electrons thus freed attach themselves to the electrically neutral dust particles, which are then attracted to the positive or

collecting electrodes. Space will not permit of a full description of this type.

Filtration Plants. The filtration of dust-laden gases is usually achieved by passing them through fabric screens or bags, the dust being retained on the side by which the gases enter. Bags are generally used, as they lend themselves to compact design. The materials from which the bags are made is dependent on the class of dust to be dealt with. Usually they are made from woven cotton, wool, or linen. The texture of woven cloth is not usually as fine as that of wool, so the latter may be taken as the more efficient filter, but the back pressure set up is consequently much greater. Cotton is the cheaper of the two but will not withstand a much higher temperature than 90° C., whereas wool may be used up to 120° C. Special fabrics are obtainable which will withstand temperatures up to 200° C.

Bag Filters may be either of *pressure* or *suction* type. In the pressure type the dust-laden air is blown into the bags, and the cleaning of the bags is accomplished either by means of a shaking device or by attachments which pass over the bags, slightly compressing them and thus releasing the adhering dust.

Suction type filters differ from the pressure type, in that the dust-laden air is sucked through, leaving the dust adhering to the inside of the bags. These are usually cleaned by reversal of the air flow, clean air being blown through from a scavenging fan. A bag-shaking device is usually incorporated, and comes into operation with the fan at a predetermined bag resistance.

The disadvantage of bag filters is that as the bags become coated with dust, the pressure increases. Consequently, increased power is needed to operate the fans; but where a high recovery of dust is required, bag filters are an economical solution, and collection efficiencies in the region of 99 per cent can be maintained.

Two points to be remembered in connection with dust exhausters are: first, that air *must* be allowed to come into the building to replace what is used in the separators (this is especially important in an air-conditioned building); second, that the air finally leaving a cyclone or bag filter should be located so far from windows or other air inlets to factories that there is no chance of any dust it may still hold entering the building. Preferably such outlets should be above the main roof, so that the wind will carry off any dust that the outgoing air may still contain.

Small Filtration Unit. The Visco filter unit is another type of dust filter which is very effective for dealing with the exhaust from small grinding machines, in cases where it is not possible to connect to a large system. The unit is composed of a cyclonic collector, a collector box, and a dust filter cell.

The filter cell has expanded metal faces, the space between being filled with innumerable short ferrules of thin copper or rustless steel,

which lie quite irregularly in the cell space. They are covered with a thin film of special colourless oil. As the dust-laden air passes over the ferrules, the dust is retained on the oil film. The cells are cleaned by immersing the whole unit in hot soda water, drying, and then immersing in a bath of the special oil. An efficiency of 98 per cent is claimed, and the author has used these units on a number of jobs, with very satisfactory results.

CHAPTER VII

SAFETY

WHILST a chapter on "Safety" may appear to be rather outside the scope of a treatise on maintenance, it will be readily understood that in most factories the maintenance department includes among its duties the manufacture, installation, and upkeep of guards and safety devices: the care of cranes, hoists, and other lifting tackle; the installation and maintenance of exhausting systems for dealing with dust and fumes in special processes; and a host of other things connected with safety. This chapter is, therefore, included in the hope that it will be of some little help to Works Engineers and others.

Just over a century ago the first Government inspectors of factories were appointed under the Factory Act of 1833. These early pioneers in the safety movement had undoubtedly a most thankless task to perform, when the ignorance and prejudices of that period are considered. They had to make their own rules and regulations for the proper administration of the Act, and each inspector made orders for his own district, dealing with the keeping of registers and time books, the granting of certificates of age for young persons and children by the surgeons, and the granting of certificates for school attendance. Compulsory education and registration of births were, of course, unknown before the Act of 1833; in fact, it may be mentioned here that compulsory education was not brought into force until 1870, when elementary schools were established.

The Factory Act of 1844 was the first big step towards dealing with the question of safety in factories. It applied to most of the textile factories, with the exception of those making lace. Under this Act, certifying surgeons were appointed by factory inspectors; notification of accidents became compulsory; women, children, and young persons were prohibited from cleaning shafting and transmission machinery while this was "in motion for the purpose of propelling the manufacturing machinery"; the fencing of flywheels, hoists, transmission machinery, etc., became compulsory; and power was given to the factory inspector to notify the occupier of a factory concerning the fencing of dangerous machinery. Moreover, the Secretary of State had power to institute proceedings against the occupier, should any person receive bodily injury as a result of machinery being unfenced.

There was a considerable amount of opposition to these measures by the occupiers of factories, but after the passing of the Act of 1856 a penalty could be imposed if fencing was not carried out, whether an injury occurred or not.

Further Acts were passed in the years 1861, 1864, 1867, 1870, and 1871, the effects of which were to include practically all factories employing fifty or more people; and the duty of enforcing the Workshop Acts was transferred from local authorities to inspectors of factories.

A Royal Commission sat in 1875–6 and a Consolidation Act was passed in 1878. This controlled nearly all the manufacturing industries, and divided them into textile factories, non-textile factories, and workshops. The extended use of the steam engine, and the increasing use of machinery generally, made it necessary to widen the scope of the factory inspectors' duties, and the occupiers seemed to be more ready to carry out their obligations than formerly. This was more noticeable on the passing of the Employers' Liability Act of 1880.

From that time until the present day the idea of safety in industry has been growing steadily, partly owing to the growing enlightenment of the people connected with industry, and partly owing to the greatly increased necessity for safety measures on account of the modern developments both in machinery and processes, and the amount of unskilled and semi-skilled labour engaged therein.

Safety Organization. The first essential to safety in any industrial concern is that the management should take a keen and intelligent interest in it. Encouragement from those in charge penetrates through all departments, and ultimately the idea is implanted in the minds of the workpeople, where it is most effective.

The second essential is the appointment of a safety engineer, who will employ all or part of his time on safety work, according to the size and nature of the establishment. He should be in close touch, on the one hand, with the ambulance superintendent, from whom he will get information concerning the nature of the accidents; and, on the other, with the maintenance department, which will carry out most of his recommendations.

Safety Engineer's Duties. The safety engineer should make a regular inspection of the factory or workshop, including all plant, machinery or gear, with a view to guarding any danger spots, and ensuring that all safety appliances are in an efficient state and are properly used.

He should have prompt notification from the Plant Office of the installation, of transfer or removal of such plant, machinery, or gear, and any alteration or extension to buildings, so that he may give special attention to these changes.

He should be responsible for fostering among the staff and workers a due appreciation of the necessity for avoiding dangerous practices, and of making use of guards and safety appliances; and employing machine-stopping devices in case of emergency. He should see that the regulations under the Factory Acts are observed, and keep himself posted in all the changes and new regulations that

may apply to his particular industry. He should have appropriate notices posted, warning workers against dangers and dangerous practices, and encouraging them to have all injuries attended to at once, however slight they may be. He should investigate every accident of any consequence, and certainly every accident which is notifiable to the factory inspector, as soon as possible after the occurrence, and should take all proper steps to prevent the repetition of avoidable accidents.

He should keep records of the work done on these lines, and also any records required under the Factory Acts.

Where the size of the firm does not warrant the whole of a man's time being devoted to safety activities, it is a good plan to combine his safety work with that of machine tool inspection. Both these spheres have much in common.

Reporting Accidents and Keeping Records. The safety engineer works in close co-operation with the ambulance attendant; in fact, it is advisable that the latter should come under his control if a doctor is not in attendance. In large works it is usual to have a surgery and nurse, or even a doctor, whilst in the smaller factories it is usual to provide a dressing station; this is generally near the time lodge, so that the timekeeper can call the ambulance man, who is usually a St. John Ambulance or Red Cross man. The indiscriminate use of first-aid boxes in and around the different departments in a factory is not advisable, as proper care and attention may not be given to an injury which at first may be a minor cut, but which may develop into something serious, due to inefficient cleansing.

Every accident which involves loss of time through a worker being sent out, should be reported to the safety engineer without delay, in order that he can make immediate investigation on the spot, question anyone who may have witnessed the accident, and, in cases of doubt, endeavour to reconstruct what has occurred by the aid of whatever evidence may be available. This investigation should be made in company with the foreman of the department in which the accident has taken place. In the case of a really serious accident, the safety engineer should be able to call on the superintendent of the department, the Works Engineer, and even the Works Manager, to assist in this investigation and make recommendations to prevent a recurrence.

A good method in the case of minor accidents is to keep a duplicate book in the surgery, for recording information, as shown in Fig. 148. A more complete form of record card has spaces in which are inserted (*a*) how long the injured person had been familiar with the work he was doing, and (*b*) how much time was lost as a result of the injury.

The procedure should be as follows. The ambulance attendant enters details in the first part of the accident record and hands the

duplicate to the worker before he or she leaves the surgery to return to work. On returning to the department, the worker hands this duplicate to the foreman, who enters briefly the cause of the accident, and then sends the duplicate to the safety engineer to record his recommendations, if any. The record is then filed by the safety engineer.

It will be realized that in quite a number of cases it is purely a matter of chance that minor accidents are not serious and even fatal. To illustrate this point: a worker has the point of a finger slightly hurt as the result of a power press guard having been left off or badly set. It may be just a lucky chance that two or three fingers were not lost. Again, a load of timber has not been carefully

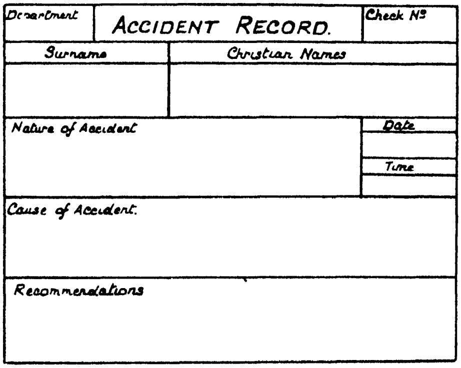


FIG. 148. TYPICAL PAGE OF ACCIDENT RECORD DUPLICATE BOOK

stacked, and a worker obtains some slight injury through the collapse of the pile. This might have resulted in a most serious accident but for some chance circumstance.

Special precautions are necessary to protect men working in tanks or boilers. The safest plan is to disconnect and fit blank flanges to all pipes through which dangerous gases or liquids might enter. As an alternative, a bypass may be arranged and two stop valves fixed (and locked shut) in the tank or boiler line. Even so, it is important to make sure that the bypass is clear before using it, and it should be blown through, as an additional test.

An important point in the foregoing method of reporting accidents is that it ensures that the foreman is fully cognizant of the nature and cause of all accidents in his department. This goes far towards checking carelessness and unsafe methods of working, and sometimes causes the suitability or otherwise of certain workers for the work they are engaged in to be reviewed. The fact that the workers have to report to their foreman inculcates a sense of responsibility in safety matters which is somewhat difficult to achieve in any

other way. Moreover, the safety engineer receives an early report which enables him to decide what investigation is necessary, and he has a personal record of each worker which will be of value to him as a means of identifying workpeople who are prone to accidents, and of finding out weak spots in working methods which lead to them. The ambulance superintendent has also a personal record of the nature of the accidents treated in the surgery. The accident record form shown in Fig. 148 is, of course, shown in quite a simple form and could be modified to suit the requirements of particular firms.

A record of the "frequency rate" and "severity rate" of accidents should be kept by the safety engineer. The frequency rate is represented by the number of accidents (of all kinds) per 100 000 man-hours worked, and the severity rate by the number of hours lost per 100 000 man-hours worked, during any period. Every three months seems a fairly convenient time to tabulate these figures, and in doing so it is advisable to divide the workpeople into groups according to the nature of the work performed. The nature of the groups would vary somewhat according to the work carried on by different firms.

A further record should be kept by the safety engineer, namely, a brief report of his regular inspection of the factory or works, and his recommendations with reference to safety of plant, buildings, processes, etc., and indeed everything that comes under his jurisdiction. A convenient method of keeping this "safety log" is in loose-leaf book form. Each department can then be kept separate and new leaves added as required. An example of a page from a safety log is shown in Fig. 149. A column is provided for the signature of the safety engineer on completion of the work carried out in accordance with his recommendations.

Points to be aimed at for safety in factories are—

(*a*) Machines should be so arranged that transport between them is a minimum, and work flows steadily from one stage to the next.

(*b*) Gangways should be wide and direct, and the rule should be strictly enforced that they must always be kept free from obstructions. White lines, to denote gangways through the shops, are an advantage.

(*c*) Machines should be provided with ample space all round. Overcrowding is dangerous.

(*d*) Arrangements should be made for the quick cutting off of the power supply in emergency, whether steam, electric, hydraulic, or compressed air.

(*e*) The lighting (both natural and artificial) should be the best possible. This also applies to stairs, passages, store rooms, etc., which are often overlooked in this respect.

(*f*) Adequate ventilation should be provided, also proper heating and air conditioning.

(*g*) Care should be taken to provide non-skid flooring.

PRESS SECTION

Date	Plant No	Remarks on condition & efficiency of guards, safety devices etc.	Recommendations	Signature
10·7·36	151	Too much space between pressure plate + table on Rhodes Guillotine	Alteration to cam to allow pressure plate to come further down	O.K. 17·7·36
18·8·36	168	No guard on centre of circular shearing m/c	Hinged sheet metal guard to top cutter + fixed guard to bottom cutter	O.K. 23·8·36

FIG. 149. TYPICAL PAGE FROM SAFETY LOG

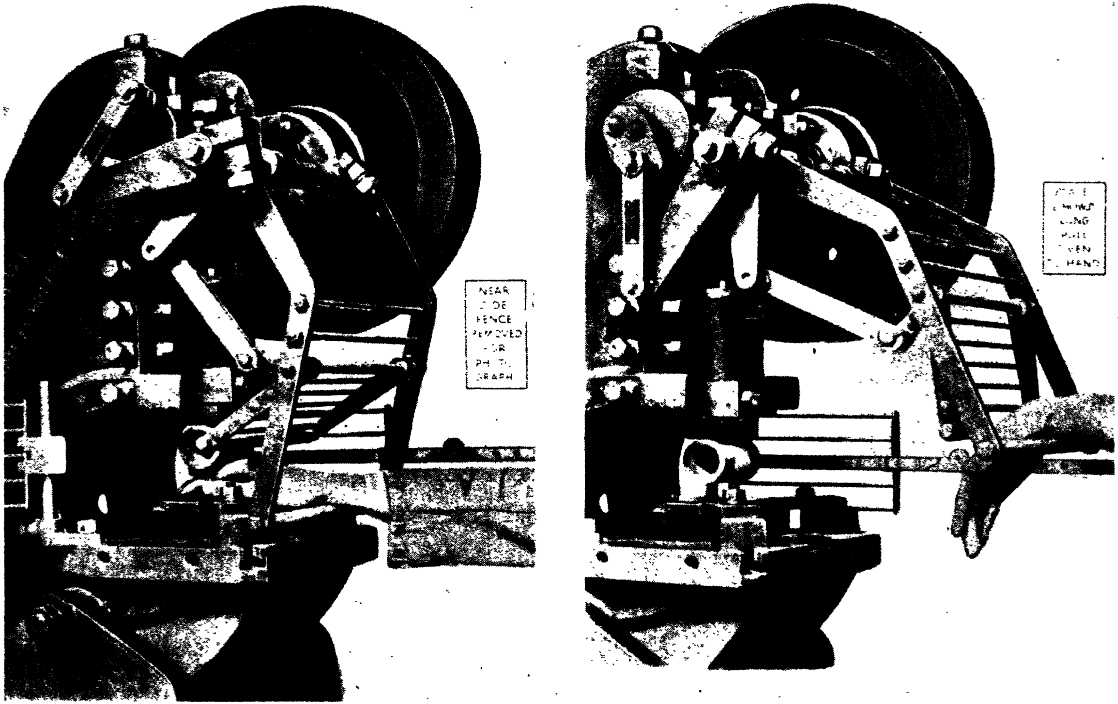


FIG. 150. UDAL PRESS GUARD

(*a*) Press at top of stroke. Operator has full access to tools.
(*b*) Press at half stroke showing special action of guard when operator leaves hand in danger.

(*J. P. Udal*)

Guarding of Plant and Machinery. While the accidents caused by moving machinery form only about one-third of the total number of accidents in industry, the necessity for efficiently guarding the moving parts becomes more and more important, owing to the increasing use of machinery, the speeding up of the machines, and the introduction of unskilled and semi-skilled operators.

It may be mentioned here that the machine speeds recommended by the makers should always be used where possible, and for machines such as power presses it is advisable to affix a brass plate clearly marked with the number of strokes per minute and the tonnage of the press. Speeds should not be increased on any

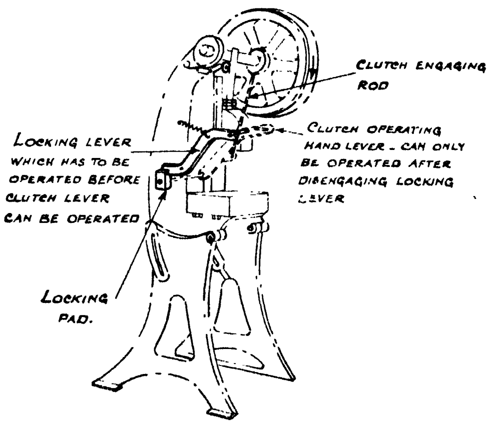


FIG. 151. CLUTCH SAFETY DEVICE ON POWER PRESS

machine without reference to the Plant Office, where all information as to safe speeds, etc., is recorded on the plant cards.

Machine tool makers and manufacturers of plant are realizing the need for guards to a much greater extent than formerly, but there is still much to be done by the designer in connection with the guarding of plant. Too often the customer who buys a new machine has to make guards for belt pulleys, shafts, and even gearing before he can start producing. This means delay, which in some instances may completely upset production plans and, in any event, is very irksome. The result is usually "a thing of parts," whereas, if proper provision had been made in the original design, the problem could have been solved much more efficiently and cheaply.

In a modern machine shop, power presses call for considerable attention from the safety standpoint, and for second-operation work the type of guard designed by the late Mr. J. P. Udal, M.I.Mech.E., of Birmingham (Fig. 150), is very efficient.

As an additional safety measure on small and medium-size presses,

it is usually comparatively simple to disconnect the foot lever for operating the clutch mechanism, and to fit hand levers constructed in such a manner that the operator has to use both hands to operate the clutch (Fig. 151). If this cannot be done, it is a good plan to fit a cover over the pedal, after the style of a hood, to prevent the pedal being accidentally depressed. The clearance between the

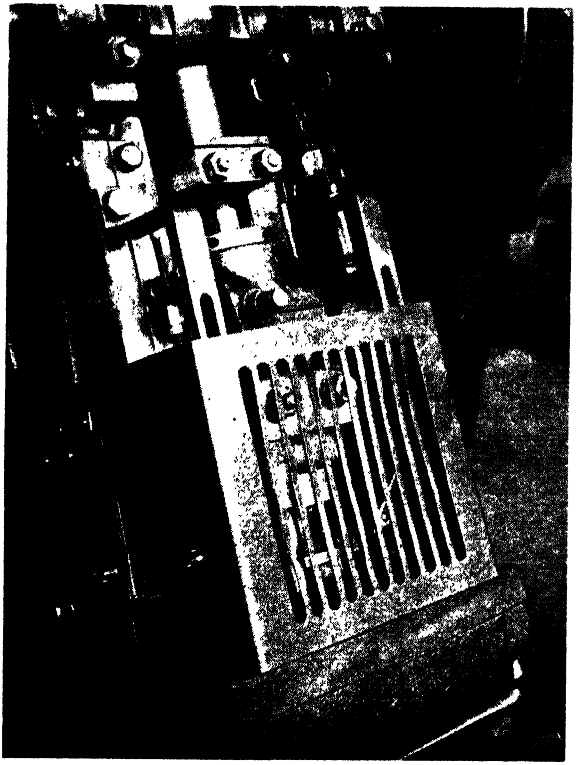


FIG. 152. GUARD FOR SMALL BLANKING STRIP PRESS (*G.E.C.*)

cover and the pedal itself should be sufficient to accommodate the operator's foot easily. Messrs. Adams Pressure Tool Co., Ltd., make a safety drop pedal, the hinged portion of which drops automatically into a safe position when the operator's foot is removed, and acts as a prop, preventing the lever from being depressed.

For dealing with blanking strip on small presses, a very efficient guard can be made from sheet metal (Fig. 152). This should be made of ample height to prevent any tendency on the part of the

operator to put his or her hands inside. A sliding piece is fitted on each side of the guard, about 2–3 in. adjustment being allowed to suit varying heights of tools. This guard has a slot large enough to admit the widest strip used. The sliding piece is shaped so that the operator can work close up to the tool in perfect safety.

On larger presses a similar type of guard of more substantial

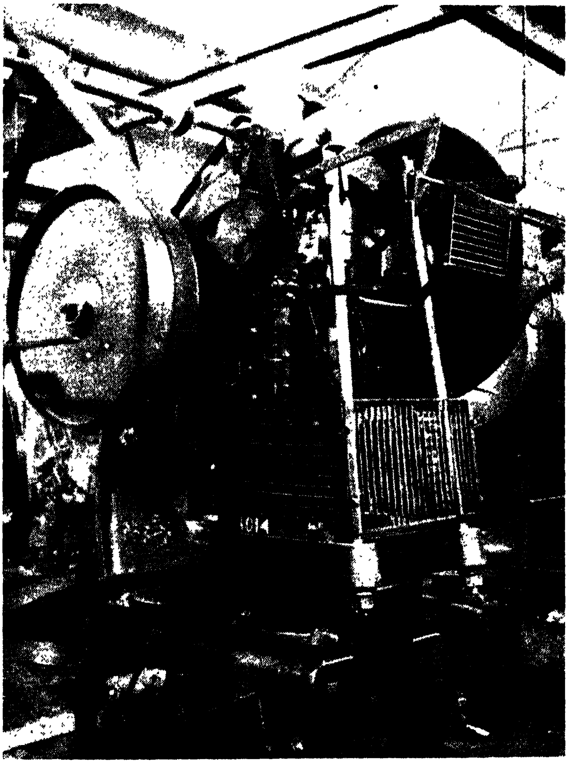


FIG. 153. BUILT-UP PRESS GUARD MADE FROM ROUND STEEL BARS
(*G.E.C.*)

make can be readily made of a mild steel frame and $\frac{1}{4}$ in. or $\frac{5}{16}$ in. round mild steel bars, riveted or spot-welded to the frame (Fig. 153). If the fitting is made in three pieces (two sides and a front), the sides make excellent guards for use with the "Udal" type of guard already referred to; provision, of course, must be made for fixing to the frame of the press.

Where blanking is done on a short-stroke press, it is usually best to have the guard incorporated with the tool.

Wherever possible, feeding devices should be adopted in conjunction with suitable guards. Various methods may be used for sheet metal presses, such as dial or turn-table feed, chute feed, slide feed, or roll feed. In these the hand is not put under the tool. Automatic feeding devices are, however, much to be preferred; these include automatic rolls for feeding metal strips, automatic

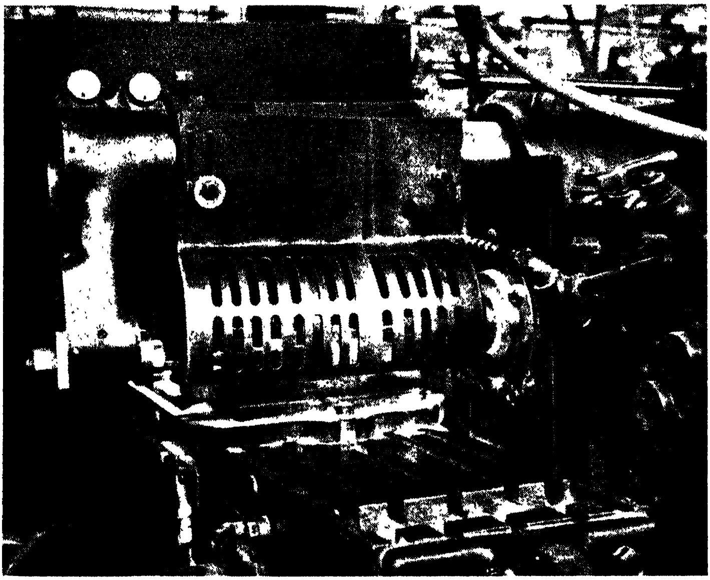


FIG. 154. GUARD FOR MILLING MACHINE CUTTERS (*G.E.C.*)

slides, "fingers" and "feeding arms," and magnetic or pneumatic attachments.

Milling machines are another source of danger if the cutter is not sufficiently protected. The large variety of work done, and the wide difference in the nature of the fixtures used, makes it impossible to design a general-purpose cutter guard to satisfy *all* conditions. There are, however, a few cutter guards now on the market, which suit a fairly wide range of work on horizontal milling machines. They are usually designed so that adjustment can be made to the length of the guard and to its position with respect to the cutter. Fig. 154 shows a simple form of general-purpose guard.

A point of danger which is frequently overlooked is that arising from the revolving end of the arbor. This can be guarded against by fitting a stationary tube over it, so that the end of the arbor revolves within the tube.

In a great many cases the nature of the work is such that a special guard is required. Too often, where the quantity of pieces to be milled is small, it is left to the setter to "rig up something." That "something" usually consists of a piece of bent tin tied up in a hurry, and it is lost by the time the next batch of pieces comes round, perhaps a few months later. Much can be achieved if the tool designer gives some consideration to the question of guards when designing the fixtures. Furthermore, when a special guard is made, it should be located in the tool store with the tools, and should be issued with the tools for the job. This ensures that it will not be lost or altered to suit some other special job, as is liable to happen if it is kept in the department.

When extensions are required to the spindles of drilling machines, they are usually keyed together, and also keyed to the machine spindle. If the key or pin projects from the spindle at all it can be exceedingly dangerous. If possible, the whole spindle should be fenced in; if this is not practicable, then at least the keys or pins should be fitted so that they can be driven home flush with the outer surfaces of the spindle and its extensions.

Figs. 155 and 156 show a type of guard which is useful in connection with a screw-slotting fixture. As the illustrations show, the guard is made in two pieces, one fixed and the other hinged. The hinged portion is held in the closed position by a projecting piece of flat spring steel, and thereby protects the operator while screw is being inserted in, or extracted from, the collet. On bringing the collet containing the screw to be slotted down towards the slitting saw, the hinged portion of the guard drops and exposes the saw. On returning the collet to the initial position, in order to extract the screw after slotting, the flat steel projection raises the hinged portion of the guard and totally encloses the saw again.

A similar principle is adopted on a vertical milling machine (Figs. 157 and 158), in which the hinged portion of the guard is retained in the closed position by means of a flat spring (attached behind the hinge, out of sight in the photographs), and is pushed open when work is brought towards the cutter.

An interesting case of unsuspected danger and the method of dealing with it is shown in Fig. 159. View (*a*) shows a horizontal milling machine immediately after an accident in which the operator lost two fingers. The machine is set up for cutting pieces accurately to length from bar stock. An apparently satisfactory cutter guard is mounted on the overhanging arm. The operator, in wiping swarf from the machine with a large piece of rag, got the rag entangled on the cutter, with the result stated. In (*b*) the machine is shown with the guard removed from cutter.

The method adopted to obviate this danger is shown in (*c*) and (*d*). The guard consists of a sheet-metal box entirely enclosing the cutter and the work in the machine. It is fixed to the milling table

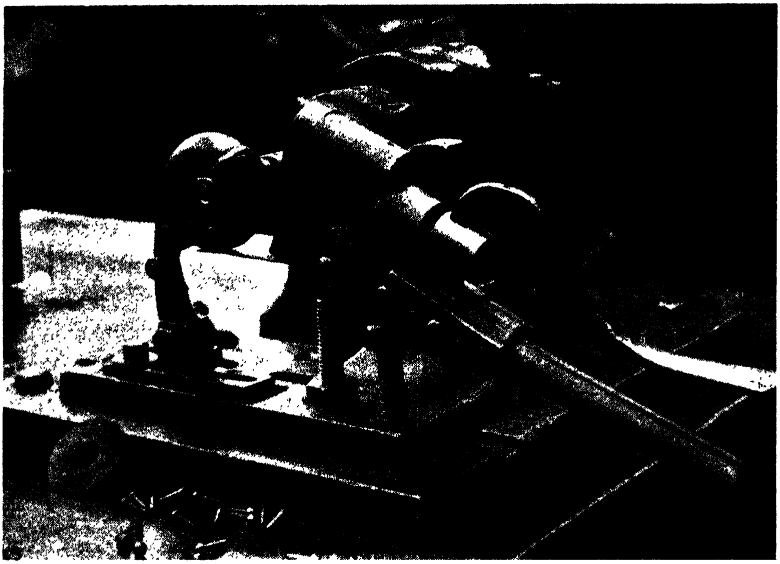


Fig. 155. Guard for Screw-slotting Fixture
Slotting saw covered.
(G.E.C.)

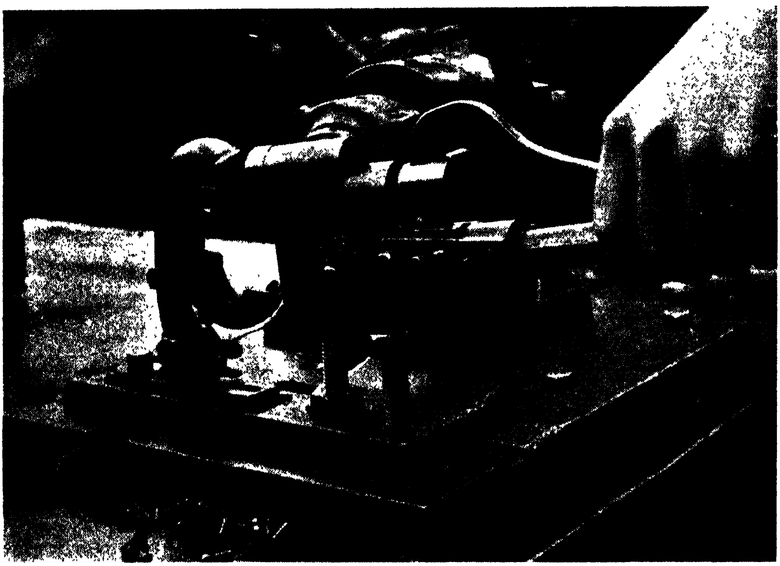


Fig. 156. Guard for Screw-slotting Machine
The hinged portion is dropped, exposing the saw whilst in operation.
(G.E.C.)

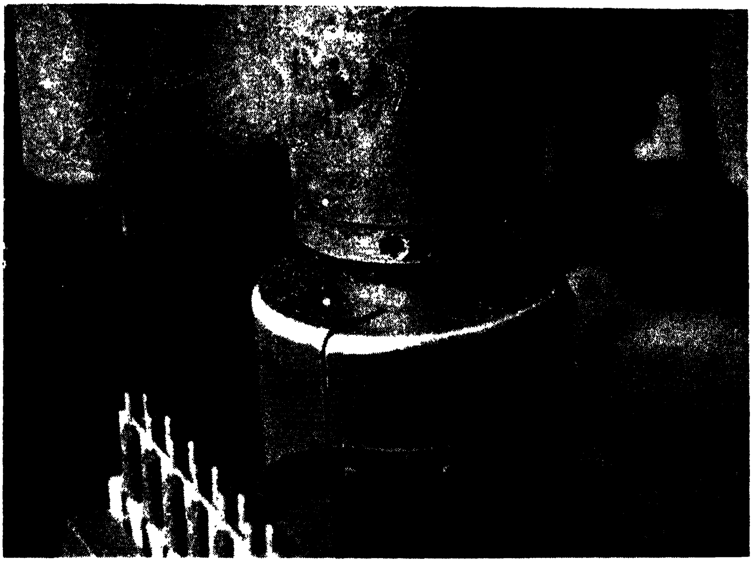


FIG. 157. GUARD FOR VERTICAL MILLING MACHINE
Work clear of cutter; guard in closed position.
(*G.E.C.*)

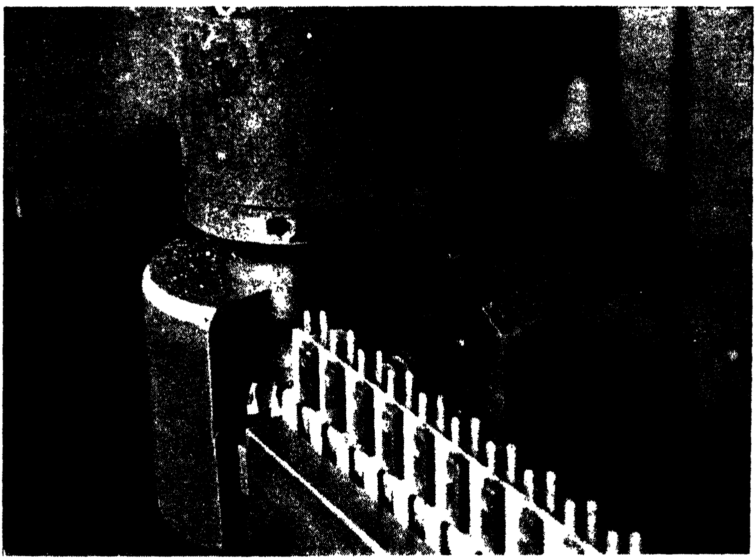


FIG. 158. GUARD FOR VERTICAL MILLING MACHINE
Work against cutter; guard in open position.
(*G.E.C.*)

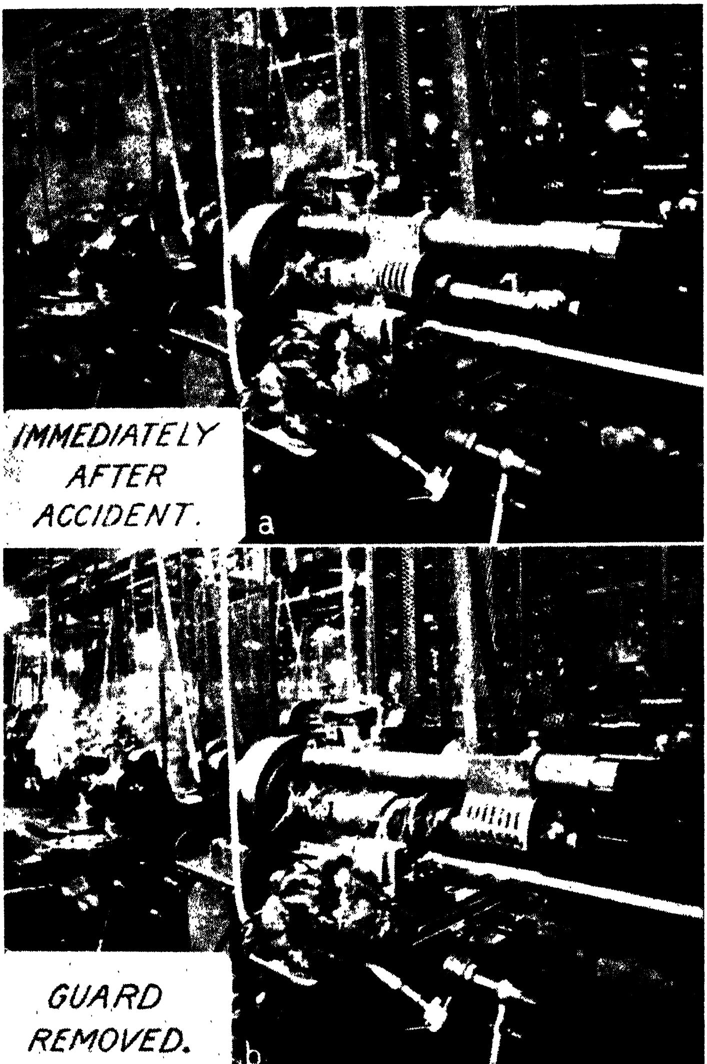
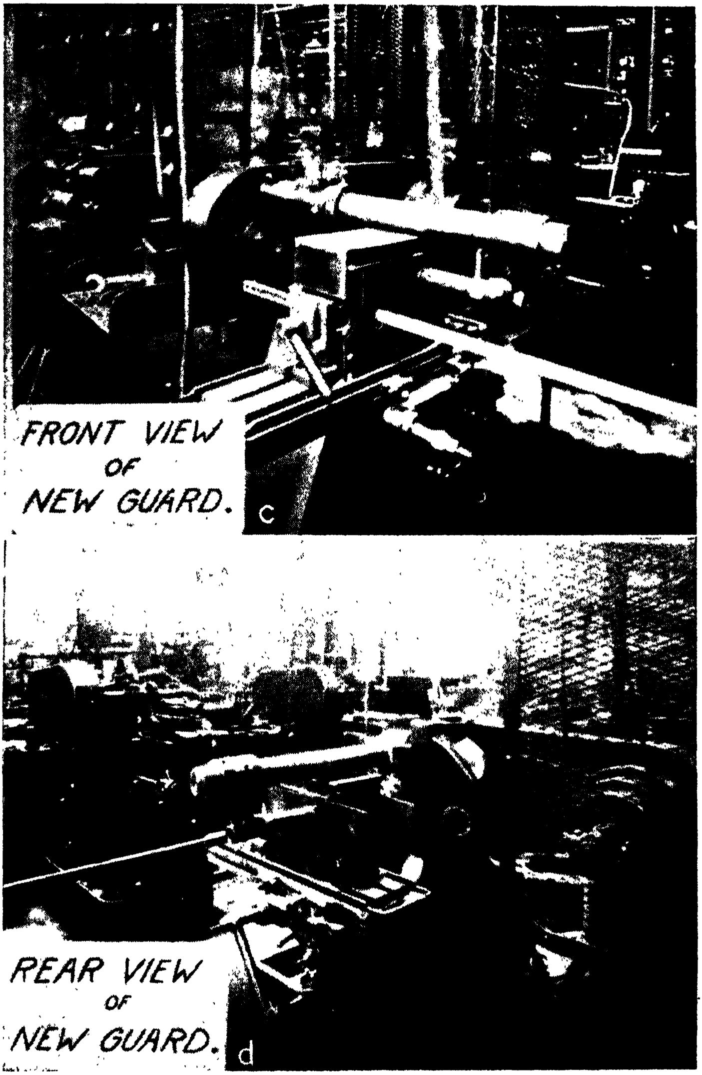


FIG. 159. METHOD OF IMPROVING THE GUARD
Used on cutting-



OF A HORIZONTAL MILLING MACHINE
off operation. (*G.E.C.*)

and has slots in each side, to allow for travel to and fro past the cutter arbor. These slots are covered by means of sliding curtains hinged to light rods fixed to the sides of the guards. A door on the end of the guard can easily be removed for clearing away swarf. The sliding curtains are, of course, made of sufficient length to ensure that the slots in the sides of the guards are fully enclosed during the whole length of traverse.

Woodworking machinery is responsible for many serious accidents. Owing to the dangerous nature of the work and the difficulty in providing really effective safety appliances, it is incumbent on everyone engaged on this class of work to exercise every care, and to use all the safety devices at their disposal. Where a large variety of work is carried on, the dangers on machines such as the saw bench and moulding spindle (to mention only two of the worst) are ever present.

It is very important to provide satisfactory heating arrangements in the wood mill, where the continual handling of different pieces of timber very soon causes numbness of the fingers in cold weather. A good floor is also highly desirable, in order that woodworking machinists may have a firm foothold.

There is no general consensus of opinion on the most suitable type of flooring for industrial workshops. The Home Office Industrial Museum, Westminster, contains specimens of three chief types—

(*a*) Wooden blocks covered with woven coarse cotton fabric.

(*b*) Glue-covered floor, on which either carborundum dust or sharp sand is sprinkled.

(*c*) Artificial carborundum tiles bonded by a clay mixture, kilnhardened.

Another specimen shows a floor of cast iron slabs having a specially roughened surface.

Magnesite flooring with a top dressing of carborundum has been found very satisfactory. "Stelcon" slabs are sometimes chosen, especially for heat-treatment shops, where heavy pots are being unloaded. This floor must, however, be kept dry to prevent splintering due to heat.

The foundry is another department where the nature of the work makes serious accidents possible. Here, as in the woodworking shop, attention should be paid to keeping the floor in good condition and free from obstruction as far as possible. Good lighting is another factor making for safety. Suitable protective clothing, including "Blucher" boots and asbestos spats, should be provided, and, where possible, goggles made of unsplinterable glass should be worn.

Cranes, hoists, and all lifting tackle are responsible for many serious mishaps, and a regular periodic inspection of these appliances should be made by some responsible person, who should also

see that all chain slings are regularly annealed. A small brass disc, on which is stamped the maximum load, should be attached to all chain slings.

It is often most difficult when giving orders to the crane driver in a noisy, badly lighted shop, to make sure that these instructions are properly understood. It is a good plan to have an experienced slinger to carry out all attachments of the crane hook, and to give all commands to the driver; where this can be arranged, it is safer than expecting the latter to be at the call of all and sundry in the shop. A standard signal chart should be fixed in the shop in a prominent position.

A regular inspection should be made of all exhausting systems, such as are used on dry-grinding machines, sandblasting or wood-working machinery, cellulose-spraying plant, etc. A simple test of the efficiency of the system can be made by the use of the water gauge described in Chapter VI.

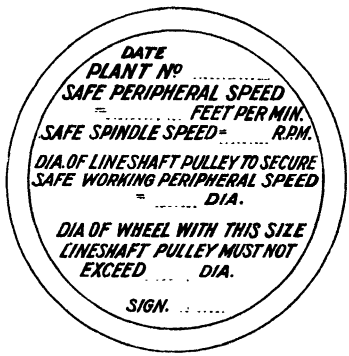


FIG. 160. TYPICAL DISC FOR AFFIXING TO GRINDING MACHINE

Ladders, if not properly maintained, are a source of danger; and employees should be encouraged to report any loose rungs, warping, or other defects. Ladders should be fitted with some form of non-slip feet. Swivelling rubber shoes can be obtained for ladders used indoors, and spiked shoes are suitable for outside work.

The fencing of transmission machinery can be carried out according to the needs of the various works, but as a general principle all overhead repairs, wiring, oiling, etc., which necessitate working near lineshafts and pulleys, should be carried out while the machinery is stopped. At least one useful belt-mounting pole is on the market fitted with spring-controlled swivelling end; and in cases where belts are too heavy to be mounted by means of a pole, the shafting should be slowed down to not more than 6 r.p.m.

Grinding machines are occasionally responsible for serious accidents owing to lack of care in examining the wheels for faults before mounting, or, alternatively, to bad mounting of the wheels themselves. Fig. 160 shows a specimen of the information which should be engraved or stamped on a brass disc and fixed to the machine.

Abrasive wheels should be frequently dressed so that the surfaces are kept true. This will do much to reduce accidents resulting from the operators' fingers becoming trapped between the wheel and the rest. Protective flanges are often fitted. The wheel section tapers

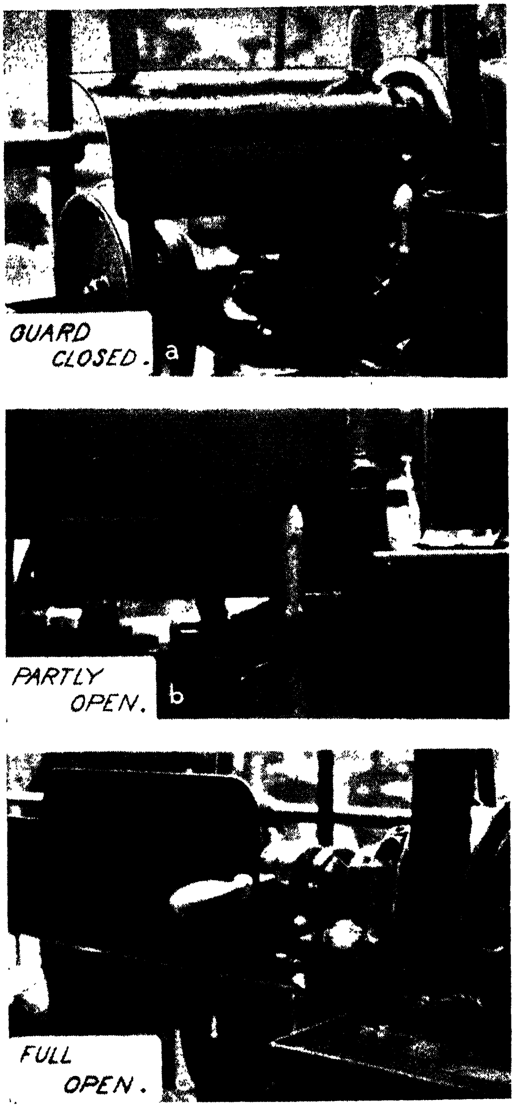


FIG. 161. INTERLOCKING TYPE OF GUARD FOR BROWN & SHARPE AUTOS

(G.E.C.)

towards the periphery, and the closely-fitting flanges prevent any portions of a broken wheel from flying out. The taper is $\frac{3}{4}$ in. to the foot. Newly-mounted wheels should be given a five-minutes' run with no person in dangerous proximity.

In connection with the design of guards, ample strength should be aimed at. Too often one sees guards much too flimsy for the requirements. Even sheet metal shields are often made of material about 18 I.W.G. in thickness, when $\frac{3}{32}$ in. or even $\frac{1}{8}$ in. would be more suitable. Loose pieces should be avoided, as they are usually lost. As far as possible, the guard should be made so that it will not be necessary to remove it, or any part of it, during normal working. Many accidents have been caused through the removal of some part of a guard or safety device for one purpose or another and forgetting to replace it.

Where it is practicable, the "interlocking" type of guard is very effective. The example given in Fig. 162 is designed to protect the worker from danger from the feeding mechanism on Brown & Sharpe automatic screw machines. View (*a*) shows the hinged metal cover over the feeding mechanism. In (*b*) the cover is seen partially open. At this point the cover has come in contact with the starting lever. Before the cover has fully opened to expose the feeding mechanism, the starting lever has been pushed over to the OFF position, and the spindle has been stopped. This position is shown in (*c*). As will be seen from the last view, the starting lever cannot be moved again until the cover has been put back in the SAFE position.

Water-level Indicators. The importance of fitting boiler gauge cocks with automatic ball valves cannot be over-emphasized. In the event of the gauge glass bursting, these valves come instantly into action, automatically shutting off both steam and water.

Electrical Plant. The Home Office Electricity Regulations should be every firm's guide to safety in electrical matters. In the case of firms which do not employ their own electricians, care should be taken to see that these regulations are complied with by outside contractors.

Industrial Diseases. Many treatises have been published on this aspect of industrial safety, but it is only possible here to mention a very few of the dangers met with in the engineering and allied trades.

With the introduction of so many new industrial processes in recent years, a careful watch should be kept at all times so that any harmful effects on the workpeople may be observed and means devised to overcome or at least to minimize such effects.

One of the difficulties in dealing with industrial diseases is the length of time which often elapses before the cause of the trouble is definitely traced to the process in which the worker is engaged. In most cases of accident it is a comparatively simple matter to

arrive at the cause immediately after the occurrence, but a worker may be engaged for years on some process before any ill-effect is apparent, and even then the trouble may not be attributed to an industrial process at all.

Silicosis is one of the industrial maladies which must have been all too prevalent in certain trades for years, but its full significance is not generally realized except by the medical profession and Home Office officials. So far as the engineering trades are concerned, this disease appears mostly among employees engaged in the grinding of metals and sandblasting, more particularly the latter trade. Some idea of the importance of taking every precaution may be obtained from a study of particulars contained in the *Annual Report of H.M. Chief Inspector of Factories and Workshops for the Year* 1932 (page 105). It will be seen from these figures that the average life of those who died of silicosis is 10·3 years at sandblasting; and of those who have died of silicosis with tuberculosis, 8·3 years. This simply means that if a young man of 20 starts work on sandblasting, the chances are that it will kill him by the time he is 30.

The remedy is to eliminate sandblasting altogether. It has been proved that most jobs that are sandblasted can be just as cheaply and effectively shotblasted, by which process the danger of the worker contracting silicosis is greatly reduced.

Where shotblasting is impracticable, the following precautions should be taken to minimize the danger of contracting silicosis—

(1) The cabinet should be periodically inspected and kept in a good state of repair.

(2) The exhaust should be capable of changing the air inside the cabinet five to ten times per minute.

(3) The exhaust should be kept continuously running whether sandblasting is actually taking place or not.

(4) Where the operator is working outside the cabinet, the blasting pressure should not be higher than that necessary for the work in hand, and should be turned off altogether for at least half a minute before opening any door in cabinet.

(5) Helmets should be of a good pattern and supplied by a reliable maker, and should be periodically inspected.

(6) The air supply in helmets should be pure and under constant pressure.

(7) No operator should be allowed to enter a sandblast chamber without a helmet, nor to remove the helmet until well clear of the chamber.

(8) Helmets should be thoroughly cleaned every day.

(9) A separate helmet should be provided for each operator.

Asbestosis is a disease similar to silicosis except that the latter is caused by breathing fine silica dust into the lungs and the former by breathing fine asbestos fibre. The results are much alike. The

remedy is the complete covering of the machines, efficient dust exhaust systems, and liberal exhaust ventilation in the workshop.

Dermatitis affects some workers in engineering and other trades. This is a skin trouble which usually appears among workers using cutting lubricant on automatic machines, and those engaged in any process where naphtha, turpentine, paraffin, or some similar substance is used. These substances have an irritant effect on some skins and allow bacteria to enter the skin, and boils or sores then appear.

Personal cleanliness among the workpeople is probably the most effective safeguard, but workers who are prone to dermatitis should be given other work where they will be free from the irritant.

The use of a centrifugal oil purifier for cutting lubricant will help to minimize the danger of dermatitis among machinists. In the purifying process the oil is heated to 180° F., and all the very fine swarf, which is liable to start irritation, is removed.

There are various preparations on the market for treating the hands and arms before starting work. These help to protect the skin during work, and are easily washed off. The following lotions are recommended by the Home Office for use after work—

(1)	Chlorinated lime (powdered)	175 grains.
	Bicarbonate of soda . . .	350 ,,
	Boric acid . . .	35 ,,
	Water	30 ounces.

(2) Dakin's Solution, which consists of "Liquor Sodae Chlorinatae cum acido borico (B.P.C.)," obtainable from any chemist.

Whichever of these lotions is used, it should be mixed with ten times the quantity of water, and the hands and arms washed with it; this should be followed by thorough rinsing with soap and water. The risk of the occurrence of dermatitis can be much reduced by providing workers with armlets extending from wrist to elbow, and strong rubber gloves.

While the advice of a doctor is desirable when dermatitis is present, treatment with calamine lotion is recommended in suspected cases.

Chrome rash, which is contracted by workers employed on chromium plating, is really a form of dermatitis, and information for guarding against this is contained in the *Chromium Plating Regulations* (dated 1st June, 1931).

The skin ulceration caused by the fumes and spray arising from chromium-plating tanks can be largely reduced by efficient exhaust ventilation around the tank, which should be provided with a hood at one end; by providing workers with rubber gloves, armlets, etc.; by installing adequate washing accommodation; and by the periodic inspection of the workers' hands and forearms, as well as their gloves and armlets.

Cellulose spraying is so much in evidence to-day that it is well to give a word of warning concerning these solutions containing more than 15 per cent by weight of benzol. As there are a number of less harmful solvents in general use, benzol should be rejected on principle on account of the danger of benzol poisoning. Strict regulations are issued by the Home Office regarding cellulose spraying, especially in connection with the design and position of the spraying shed, the equipment of the operator, and the continual changing of the air in the shed itself.

Trichlorethylene is in fairly general use now as a degreasing agent and, where this solvent is used, care should be taken to see that the makers' instructions on the use of the plant are carried out, in order that workers may not suffer from the narcotic effect of the vapour. The latest type of plant, with the cooling coil housed in the degreasing chamber and a "cold line" or water-jacketed strip running round the chamber itself, is an improvement on the older type with the cooling coil in the lid of the plant.

Danger of explosions in various processes, such as oxy-acetylene welding, should be guarded against as far as possible by ensuring that those concerned are fully conversant with the proper use of the material and plant with which they work.

In conclusion, anyone responsible for safety in workshops or factories cannot do better than to make full use of the wealth of information contained in the various Home Office publications, a full list of which is available in *Form* 101. *List of Official Forms, etc.*, obtainable from H.M. Stationery Office.

It is advisable, when in any doubt on matters which may affect the safety, health, or welfare of employees, to get into touch with H.M. Inspector of Factories for the district in which the works are situated; any available information on the matter is freely given.

Industry in Britain pays for what is undoubtedly the finest civil service in the world. Industry will be well repaid by making full use of this service. In this connection it would be an advantage if the administrative staffs of all workshops and factories could pay a visit to the Home Office Industrial Museum and Exhibits, 97 Horseferry Road, Westminster, London, S.W.1, where they would see what can be done, and indeed what progressive firms are doing, in the direction of industrial safety and welfare. For those who cannot visit this really practical institution, much useful information is contained in a descriptive account and catalogue, which can be obtained for 3s. 6d. from H.M. Stationery Office.

CHAPTER VIII

FIRE BRIGADE AND FIRE EQUIPMENT

Fire Brigade. In a large works a works fire brigade is essential, since it is the first few minutes that count in an outbreak of fire. If some of the employees have had training in fire-fighting, thousands of pounds may be saved by dealing promptly with the outbreak. Added to this is the saving effected by the reduced insurance premiums payable when there is a works fire brigade. Moreover, the dislocation of business caused by a fire, with resultant unemployment, can be avoided.

When a works brigade is being formed, the chief officer of the local city or town brigade will always give his advice and help. In most districts to-day there is an Association of Works Brigades, and the author has always found that every assistance is given to a new brigade. When the brigade has been formed, affiliation to the National Fire Brigade Association (N.F.B.A.) is recommended (the annual subscription being £1 10s.), as apart from the benefits that accrue, it puts the brigade on a proper footing.

The brigade should consist of a first and second officer and firemen, the total strength depending on the size of the works. There should be one drill night per week, for which the officers and men should be paid (say, half-yearly). Uniforms should be supplied. The station duty book, supplied by the N.F.B.A., makes an ideal drill attendance book, and should be initialled by the commanding officer each drill night. The brigade should be encouraged to compete in the local fire brigade tournaments, as this makes the men keen. After a time the various brigades become just as keen as the works cricket or football team, and the extra hours which they will devote to training will more than recompense any time or expenditure that may accrue. With a new brigade it is a good plan to offer an Efficiency Cup to be competed for annually, by teams of, say, two or three men in the brigade. First aid should also be made part of their training.

In a large works it is usual to keep at least one full-time fireman, who patrols the premises during working hours, keeps the appliances clean, and sees that clear access is kept to all hydrants and emergency doors.

Suitable instruction sheets (Fire Notices) should be posted in the works, a representative sample of which is shown in Fig. 162.

Fire Alarms. The best method, of course, is to install a proper fire alarm system using ordinary "dolly" switches or "pull" type switches; standard "break glass" "spring" switches should not be used in war-time, as due to blast the glass may break and give false alarm. The system should light an indicator lamp showing

FIRE NOTICE

TO ALL FOREMEN

Fire alarm pushes on a signal red background are situated at the following points—

Time Lodge	Timber Works	Rubber Factory
Main Corridor	Varnish Room	No. 3 Factory
Main Shop Corridor	Main Assembly	No. 3 Factory Yard
Gate House	Heat Treatment	Impregnating Works
	Central Stores	

There are.... ...... (*state No.*).... ......outside alarms .... (*give locations here*)

IN THE EVENT OF AN OUTBREAK OF FIRE during normal working hours—

1. Break glass of nearest fire alarm box and stand by until brigade arrive to give actual position.
2. Shop foremen should at once see that their workpeople are clear of the affected area. Do not let them wait to collect tools or clothing if there is the slightest danger.
3. Switch off all electricity and gas under your charge.
4. Foremen in the affected area should act as police and keep all gangways clear.
5. Do not use water unless necessary: try the chemical extinguishers and sand. Water causes a lot of damage.
6. Only use "Pyrene" extinguishers or sand on electrical fires. See that these extinguishers are refilled after use.

ALL MAIN CORRIDORS, GANGWAYS, FIRE ALARMS, AND HYDRANTS *MUST* BE KEPT CLEAR

TO WATCHMEN

IN THE EVENT OF AN OUTBREAK OF FIRE, Watchmen must—

1. Break glass of nearest alarm to the outbreak.
2. See that all gates and doors in the affected area are unlocked immediately.
3. Give the alarm by push button on No. 2 Works Steam "Bull."
4. Ring up Works Engineer and Chief Officer.
5. *Open Works Road Gates.*

Emergency Keys for these doors are hung in Time Lodge.

Boilerman to blow three blasts on No. 1 Works "Bull" *after* working hours (two short blasts and one long).

WORKS FIRE BRIGADE

RANK	NAME	Section
Chief Officer		
2nd Officer		
Fireman		
Fireman		

FOREMEN ARE AT ALL TIMES WELCOME TO ATTEND FIRE DRILLS

FIG. 162. FIRE NOTICE

the actual shop where the outbreak has occurred, at the same time switching on the fire "Klaxons." The indicator board is located at or near the fire station, which should be as central as possible. A typical system is shown in Figs. 163A and 163B.

AUTOMATIC FIRE ALARMS. These are arranged to give notice whenever a fire occurs, or where the temperature rises to a dangerous height. There are two principal types: (*a*) *thermostats*, which can be adjusted to work at any predetermined temperature; and (*b*) *sensitive tube* systems, containing air or fluid, which expands on being heated, and so operates the alarm.

The indicators must be robustly constructed, so that exposure to dust or to the atmosphere does not render them inactive. Where the expense of installing such systems is not permissible, foremen and shop clerks should be instructed to ring the branch exchange, stating "Fire Department"; the operator would then ring a code signal (say, two short rings at periods of half a minute) on a push button connected to the works time bells, and inform the fire station of the position of the fire by means of the telephone.

Insurance Rebates. The fire insurance companies allow substantial rebates if first-aid fire appliances are installed to their requirements as follows—

Five per cent Rebate. Portable chemical extinguishers, having an aggregate water capacity of 2 imperial gallons for each 250 superficial yards or part thereof, but not less than 4 imperial gallons on each floor, the water capacity of an extinguisher being not less than 1 imperial gallon or more than 3 imperial gallons. Special liquid hand-pump extinguishers of not less than 1 quart capacity (such as "Pyrene," "C.T.E.," etc.) allowed when used in conjunction with the soda-acid type, and forming up to 50 per cent of an installation. One special-liquid extinguisher is considered equivalent to a 2-gallon "soda-acid" extinguisher; or

Two or more fire plugs and hydrants, as above, but without a hydrant on each landing or each floor;* or

Fire buckets of not less than 2 imperial gallons capacity each, always filled with water, and numbering three buckets to each 250 square yards of floor or part thereof; but not less than 6 buckets on each floor.

Seven and a Half per cent Rebate. Two or more fire plugs or hydrants in the yard and at least one hydrant (minimum diameter 2 in.) on each landing of the staircase, as well as one on each floor, with adequate constant water supply.

No greater discount than 15 per cent is made for any combination of the above appliances.

The rebates mentioned in this section are only allowed provided that the insurance company's surveyors carry out periodical tests

* There must be a sufficient quantity of hose and water available at such a minimum pressure as to command the premises.

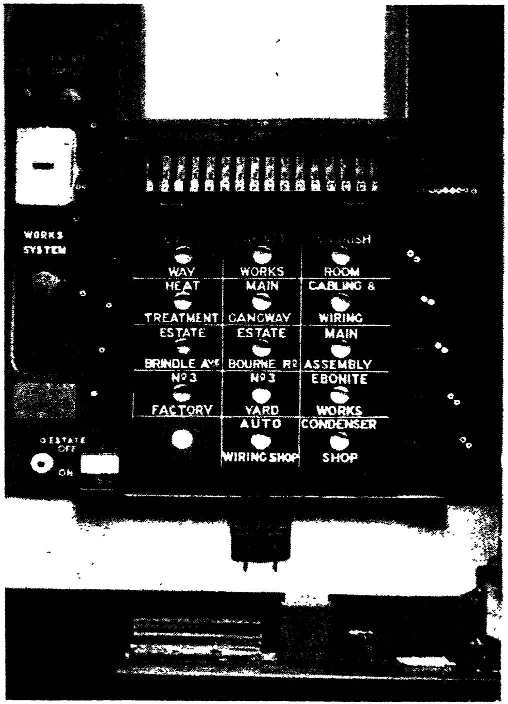


FIG. 163A. WORKS FIRE ALARM INDICATOR BOARD

As seen from inside the works

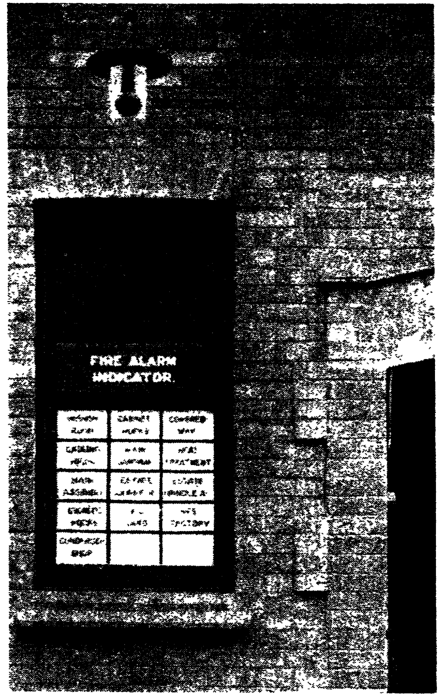


FIG. 163B. WORKS FIRE ALARM INDICATOR BOARD

As seen from outside the works

to ensure that the fire-fighting plant in the works is efficiently maintained.

The insurance companies naturally are pleased to render any assistance in their power in connection with the proposed installation of fire-fighting equipment. Although it is not the chief function of insurance to aim at the prevention of fires, the companies are obviously interested in the problem of stopping outbreaks of fire or, if once started, in limiting their scope. The Fire Offices Committee is an organization formed by insurance companies and maintained by them for the protection of their interests, and also for the framing of rules and regulations for the conduct of the business.

One of the most useful departments of this Committee is the Technical Institute at Manchester, which was erected and is maintained solely by the tariff fire insurance companies. The result of this expenditure has been the reduction of fire risk, which ultimately means lower premiums and also lessens the danger to life and limb.

The Institute is largely concerned with the examination of fireproof materials, and the strict investigation and testing of all appliances designed for fire prevention or limitation. It is at this Institute that tests have been made on all fireproof doors, fire extinguishers, sprinkler heads, and sprinkler systems made by various firms, before they are passed for the different discounts allowed. Any new appliance must also be submitted for these tests, which are very searching and exhaustive. As there are over sixty different makes of fire extinguishers alone, it will be clear that the work carried out by this Institute is very extensive. Sprinkler heads are tested for sensitiveness to temperature and for the time taken to open under varying water pressures. There is also apparatus for testing the sensitiveness and efficiency of four different types of automatic thermostats. In one building, fireproof doors are subjected to intense heat, the flame being provided by means of gas under pressure. In another building, fire-resisting floors are tested at various temperatures, rising, if required, up to 2 300° F.

EQUIPMENT

Suitable extinguishers and sand buckets, of the types best suited for individual requirements, should be fitted in every department. The following is a list of extinguishers suitable for dealing with different classes of outbreak—

Petrol, Varnish, and Celluloid. Sand and foam extinguishers (say, 2-gal. type) should be used, or carbon tetrachloride extinguishers for small outbreaks. The "foam" forms a blanket which spreads over the fire, cutting off the air necessary for combustion. The "C.T.E." or "Pyrene" type forms a heavy vapour, having the same effect as the foam.

Electrical Fires. Carbon tetrachloride extinguishers, which have a blanketing effect, should be used, as the liquid is a non-conductor.

Freely-burning Materials. The soda-acid type (2 gal.) should be used, preferably the plunger type. The fluid discharged acts like water, effecting extinction of the fire by what is known as the *cooling down* method.

A new type of extinguisher which should become very popular is the Randwell water gun and tower bucket. It comprises a special tower bucket to hold 2¼ gal. of water and a water gun, which is very easily operated. The gun can be instantly filled and can throw a jet of water about 25 ft.; a spare bucket is provided, so that one bucket can be refilled whilst the other is being used. The advantages over the soda-acid extinguishers are, first, that only enough water necessary to put out the fire need be used; whereas with the soda-acid extinguisher, once it is started the complete charge must be used up. Second, it can also be used continuously, provided that buckets of water are available; and third, more important still, it can be tested periodically without any cost for refills.

Hydrants. The usual and oldest method of extinguishing fire by water is known, as mentioned above, as the "cooling down" method, owing to the fire temperature being reduced below ignition point. For a large outbreak it is always necessary to use water, but small outbreaks should be put out if possible with small extinguishers, as very often the water damage may be much greater than the actual damage caused by a small fire. This fact emphasizes the necessity of having trained firemen when using water.

Hydrants inside a works should have hose cradles, carrying at least two lengths of hose and branch pipe. Outside hydrants should have a glass-fronted hose box, containing hose, standpipe, key and branch pipes, and, if at a position adjoining a housing estate, one or two first-aid extinguishers may be included. An inventory of the contents should be fixed in each box.

Water pressures below 100 lb. per in.^{2} gauge are not very effective, and, if there is a possibility of the supply pressure occasionally dropping below 60 lb. per in.^{2}, fire pumps are necessary to give an adequate supply. In a works where hydrant mains are laid throughout the shops a pump, which may be either steam- or electric-driven, should be installed in the mains either as a booster or, better still, to draw water from a reservoir put in for that purpose, thus ensuring an extra supply apart from the capacity of the supply authority. Where a well and water tower are provided for storage, they can be used either in conjunction with the reservoir from the supply authority or as a separate supply. The pumps start automatically if the pressure drops in the fire main, due to a hydrant being opened or a sprinkler head going off. Fig. 164 shows a system for a large works, which includes two supplies—well water and corporation water—together with a supply for a sprinkler system. The electric pump, which is driven by a 75 h.p. motor, has a capacity

of 625 g.p.m., and the steam pump capacity is 500 g.p.m. at 100 lb. per in.^{2} gauge pressure.

The electric pump is automatically operated; the steam pump is operated by hand, as it is near the boiler house. Immediately the fire alarm sounds, the steam pump is started. Should the power be off, causing a pressure drop, say in the sprinkler system which is

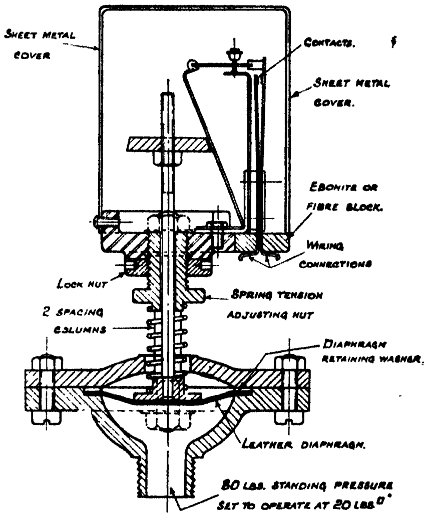


FIG. 165. ELECTRICAL ALARM INDICATOR

a quarter of a mile away, an alarm is given by the spring-loaded diaphragm shown in Fig. 165, which then comes into operation.

A typical electric pump installation is shown in Fig. 166.

Sprinklers. For warehouses or workshops where woodworking, cellulose spraying, or other highly inflammable work is carried out or inflammable material stored, the sprinkler system is, of course, the most efficient method of fire extinction, a sprinkler head being almost instantaneous in action. As soon as the temperature reaches the melting point of the fuse, the sprinkler comes into operation at the seat of the conflagration only, the blanketing effect of the spray helping to confine the fire to a small area; the water damage, therefore, is much less than would be the case if hose and nozzles were used. Again, the sprinkler heads are on guard day and night, ready to give the alarm when one or more comes into operation.

In laying out a sprinkler system, it is essential that an adequate water supply should always be available. Insurance companies accept as adequate sources of supply: town's main, elevanted tank, pressure tank, pump, injector apparatus in connection with public

or other approved hydraulic mains, or a private elevated reservoir. The two latter are allowed only after specific sanction has been obtained from the fire insurance company. The private elevated reservoir should have a capacity of 200 000 gal. if it is proposed to substitute it for the town's main.

A method frequently adopted is to install an elevated sprinkler

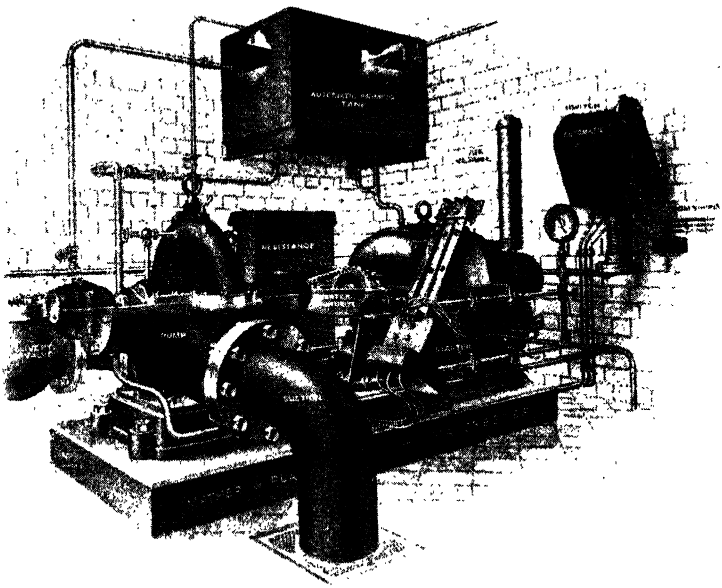


FIG. 166. ELECTRIC FIRE PUMP WITH AUTO-ELECTRIC STARTER
(*Mather & Platt*)

tank in conjunction with the town's supply; two supplies are thus available.

SPRINKLER HEADS. At least one sprinkler head must be allowed for each 100 ft.^{2} of floor area, the heads being normally fixed in the roof or ceiling. Here again it is essential to arrange for the fire engineers responsible for the scheme to confer with the fire insurance company. The same procedure should be observed with regard to the sizes of mains. Sprinkler heads usually operate at 155° F. for ordinary buildings, higher temperatures being allowed for kilns, etc. There are various fusible alloys for use in sprinkler heads, of which the following is a typical analysis: bismuth, 50 per cent; lead, 25 per cent; cadmium, 13 per cent; tin, 12 per cent. This

alloy is claimed to ensure good and even results. It is also obviously desirable that sprinklers should be able to distribute water *evenly* over the area which they are installed to protect.

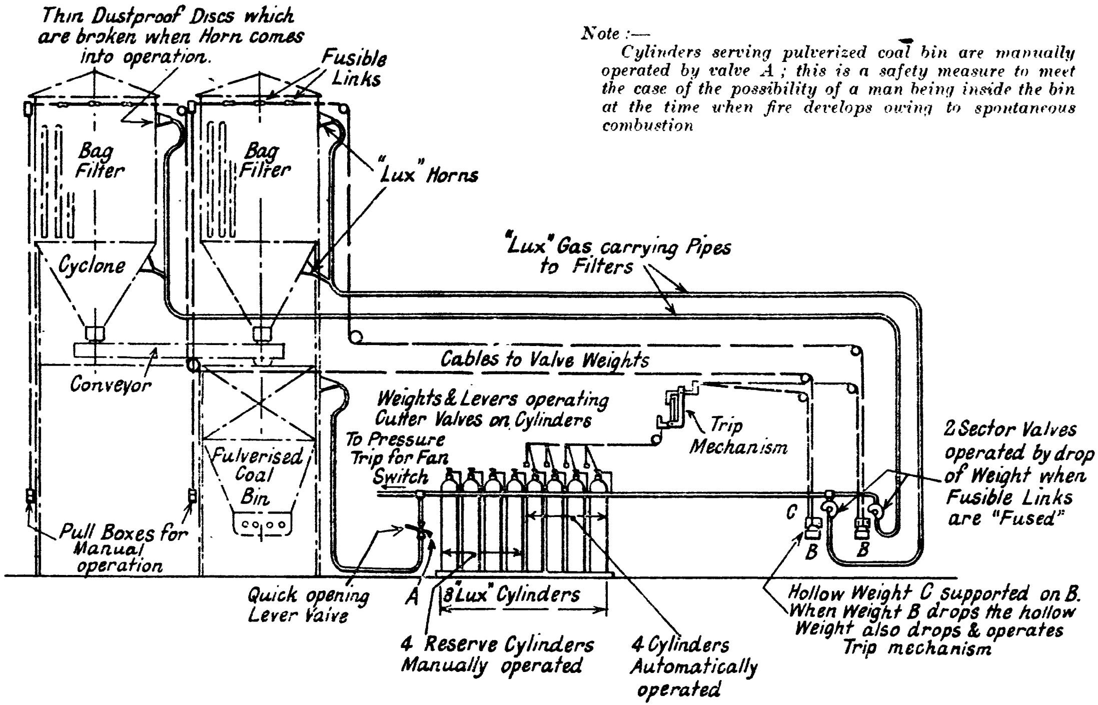
DRY PIPE SYSTEM. In buildings which are not heated, and where there is a possibility of the pipe freezing, the sprinkler system may be installed on an approved "dry" system, in which the pipes, instead of being charged with water, contain air, which is forced into them under pressure, and which thus holds back the water pressing on the valve in the supply pipe. It is necessary to fit a testing tap on the "installation" side of the air valve so that the alarm bell can be tested; it should come into operation upon a reduction being made in the dry-pipe pressure by means of the testing tap. The testing tap should be examined once a week.

PUMPS. Where pumps are installed in a sprinkler system, they must be automatic, coming into operation when the pressure in the main drops. Where the pump is above the level of the water supply, a foot valve and priming arrangement must be fitted, and a metal pipe of not less than 4 in. internal diameter for turbine-driven and 2 in. diameter for other pumps, must be permanently connected between the suction pipe and the priming tank. The priming tank should be at least three times the capacity of the suction pipe from pump to foot valve. A stop valve must be fitted on the priming pipe and should be of the same size as the pipe. The priming arrangement is shown in Fig. 164. For less than 100 sprinkler heads, the pump capacity should be 500 g.p.m.; above this number, the capacity should be 625 g.p.m.

PRESSURES. These depend on the class of installation. For a town's main a pressure of 25 lb. per in.^{2} at the highest sprinkler head should be maintained for a first-class installation, although lower pressures are accepted by insurance companies at a modified discount. The elevated tank must have its base not less than 15 ft. above the highest sprinkler head and a capacity of not less than 7 500 gal.; or a base of 20 ft. above the highest sprinkler head for a tank capacity of 5 000 gal. The insurance company or the fire engineers who put forward the scheme should, however, be consulted on this point. A sprinkler system supplied from a pump-driven hydrant system, with an elevated tank as secondary supply, is shown in Fig. 164.

CO_2 Equipment. For large pulverized fuel bins, etc., the "Lux" CO_2 system is very effective. In this system, carbon dioxide is used to extinguish the fire. Unlike water, it will cover the whole surface of the fire, and is, therefore, thoroughly effective.

A diagram of a Walter Kidde "Lux" installation on a 25-ton pulverized fuel bin is shown in Fig. 167. This installation has come into operation several times over a number of years without causing damage and without entailing the shutting down of the boilers. Coal was still being fed from the bottom of the bin during the whole



Note :—
Cylinders serving pulverized coal bin are manually operated by valve A; this is a safety measure to meet the case of the possibility of a man being inside the bin at the time when fire develops owing to spontaneous combustion

FIG. 167. "LUX" CO_2 EQUIPMENT APPLIED TO PULVERIZED COAL PLANT

time the sprinkler was in action. Small portable hand-operated types are made by the Pyrene Co. and by the Walter Kidde Co. On test, these extinguishers have proved very effective.

Foam Generators. Where large quantities of oil and spirits are kept, or where large oil-cooling tanks, oil-heated furnaces, etc., are installed, the fire hazard is somewhat different from that of the ordinary fire; and whilst special jets (such as the "Mulsifyre" branch pipe) are very effective, foam is the most satisfactory extinguishing medium. Portable foam generators for use in conjunction with

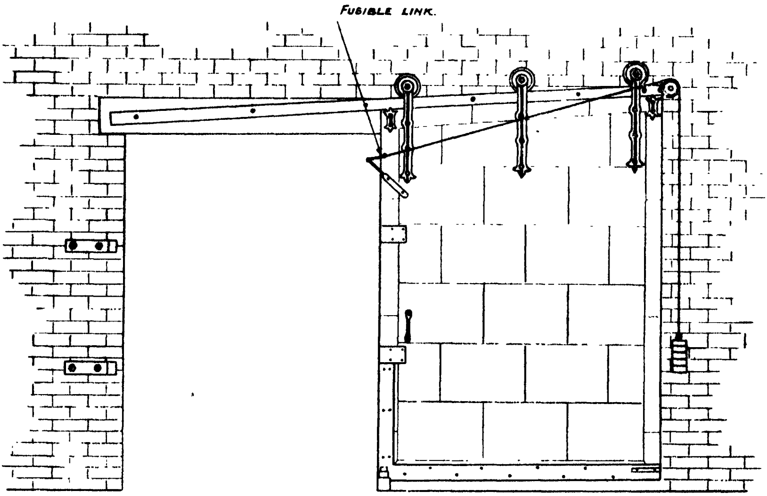


FIG. 168. ARMOURED FIRE DOOR

existing hydrant installations can be taken to the seat of the outbreak and coupled up with the hose. The "Phomene" is one of this type and is made in various sizes to deal with from 300 gal. up to 12 000 gal. with one charge.

FOAM-MAKING BRANCH PIPE. A branch pipe of this type has recently been put on the market by the Pyrene Co. It is larger and slightly heavier than the ordinary type, but is well balanced. The mixer and valve control is neatly arranged, the pipe taking the form of a Venturi tube. The "snow powder" container is strapped to the fireman's back. It can be coupled to a standard hose coupling in the usual way, and can be put straight into use. There are three sizes, producing from 250 to 1 250 gal. of foam per min. Tests show the mixing to be good, the analysis being: air, approximately 90 per cent; water, 10 per cent; foam compound, $\frac{1}{10}$ to $\frac{1}{3}$ per cent. It is possible, of course, to couple a number of these branch pipes on to any fire pump, converting it into a foam-producing unit.

Armoured Fire Doors. The use of fireproof doors for isolating one building from another brings these doors into the category of fire equipment. The type made by Messrs. Mather & Platt is of tongued and grooved pine boards treated under heat with a special preservative, ensuring them against rot. This wooden core is covered with tinned steel or iron sheets, so fastened together that they exclude all air from the core, but are free to expand without becoming detached. The special feature of these doors, compared with a steel door, is that they do not conduct the heat. Whilst a steel door will

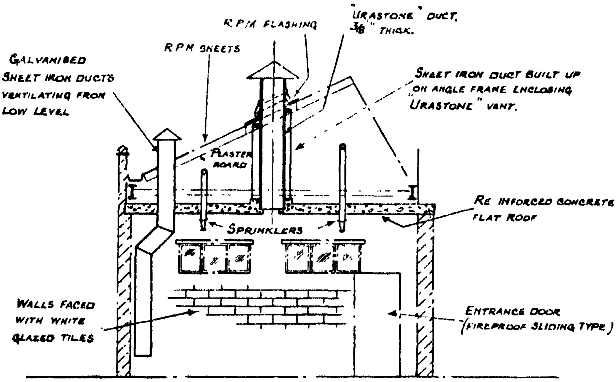


FIG. 169. STORE FOR HIGHLY INFLAMMABLE CELLULOSE VARNISHES, ETC.

soon attain an equal heat on both sides, a test on an armoured door showed that, in a particular instance, while the temperature on the "fire" side rose to 1 960° F., the maximum temperature attained on the other side was only 90° F. The author had one building (a lacquer shop) completely gutted, yet the armoured doors kept the fire from spreading to the main building, and were themselves only slightly damaged on the "fire" side.

If possible, sliding doors should be used, as it is easier to make this type self-closing, the balance weight being held by a fusible link. A door of this type is shown in Fig. 168.

USEFUL FIRE PRECAUTIONS

Of the various ways in which fire may be caused, the chief are: direct ignition from a flame or glow, electrical sparks from short circuits, focused sun's rays, friction, explosion, or spontaneous combustion. It is necessary to cover all these eventualities. Perhaps the risk that needs most watching in a large works is spontaneous combustion, which is generally due to oxidization or oxygen absorption of cellulose, impregnating varnishes, linseed oil, rags, etc.—in fact, all scrap which has the tendency to set up oxidization at normal

temperatures. Carbon in finely powdered form, such as pulverized coal, also demands adequate precautions. In many works to-day, cellulose or other highly inflammable materials are frequently used for various processes, and adequate storage arrangements must be made. Fig. 169 shows a store for cellulose varnishes. The walls are glazed to facilitate cleaning; a fireproof ceiling and sprinklers are provided. Moreover, adequate vents to the outside from top and bottom are included to ensure that heavy fumes are emitted from the ground level as well as lighter fumes from the ceiling, in the event of spontaneous combustion.

The varnishes are stored in pump containers, such as those made by the "Wesco" Products Co. The author had a flat paddle fitted at the bottom of the pump lever, in order to keep the varnish thoroughly mixed. These containers are very cheap and can now be bought with the paddle attached.

Cellulose Spraying Booths. Wherever possible, the fans should exhaust to the atmosphere, a fan being fitted to each booth. Sprinklers should be fitted in the top and also in the trunking, when the latter is of any considerable length. Booths should be kept clean; it is a good plan to cover the inside with a thick grease, spread with brown paper which will adhere to the grease. This eliminates the necessity of scraping the inside, and the paper can be replaced once a week in a very short time. Fan blades—which should not be of steel—and outlets should be thoroughly scraped and cleaned each week, a brass scraper being used, as steel may cause a spark. All varnish rags should be collected in a metal container on wheels and taken out and burned each evening. The flash point of inflammable liquids should be checked when received, as there is the possibility of a supplier sending in a liquid of a lower flash point, which may, therefore, be dangerous in the process for which it is bought. If floors are kept clean and these precautions are taken, fire risk is reduced to a minimum. The fan of a cellulose spraying booth should be left running for some minutes after spraying has ceased, in order to clear the atmosphere in the booth thoroughly.

Lightning Conductors. The zone of protection afforded by an individual lightning rod may be considered to lie below the surface of a cone having a base of radius equal to its height (i.e. a base angle of 45°, the vertical height of the cone being, of course, equal to the height of the rod). Lightning rods should be as straight as possible; there should be no loops or sharp angles. The bottom of the rod should be sunk so deep that it will always be in moist earth; or, if this is impracticable, the bottom should be connected to a large mass of metal sunk well below ground. Care should be taken to keep the earthing point well away from gas mains. If several rods are required, they should be interconnected.

Static Electricity. This may be generated by a belt passing over a pulley, oil or petrol passing through a rubber hose, or steel shot

from a sandblast. Good ventilation should be provided to carry away dangerous fumes; and in the case of rubber hose, the nozzle should be effectively earthed.

The effect of static electricity varies enormously, according to the humidity of the air. Dry air is an effective insulator, and is therefore to be avoided where there is possible danger due to accumulation of static electricity. If the air is humidified, nine-tenths of the danger disappears, whilst the remainder can be minimized by good earthing.

Pulverized Coal Storage. Bins should be protected by a CO_2 installation (page 275).

Multi-Story Buildings. Where such buildings are of fireproof construction, care must still be taken to see that wood shelving and racks, in fact, wood in any form, is reduced to a minimum, especially if the building is used as a warehouse or stores. A fire from one floor will spread upwards via the windows, which become broken owing to the heat, thus permitting the flames to "lick" into the next floor, and nullifying the effect of the fireproof construction. A water "screen" in front of all windows and doors is a good scheme if coupled with a sprinkler system installation; the combined installation is known as the *drencher* system. Wired glass or electro-copper glazing are also suitable for the prevention of fire.

Drenchers should be of the open type (unsealed) to give the best results. If the eaves are of a combustible material, they should also be protected by drenchers. A line of drenchers along the ridge of a roof is an efficient protection for the roof itself, the horizontal distance between the drenchers being not more than 8 ft. A control valve should be fitted at the base of the supply pipe to the highest drencher in any section. The supply pipes should be not less than 1 in. internal diameter, and wide-radius bends should be used instead of right-angled elbows wherever possible. The pipes for the drenchers themselves should preferably be galvanized, to reduce friction losses due to corrosion on the internal surface. Drainage of the system after use is effected by discharge pipes fitted at suitable points. To prevent the blocking of holes in drencher pipes during the external painting of the building, it is a good plan to put an ordinary tack in each hole; these are easily removed when the painting is completed.

Fume and Smoke Masks. Whilst there are suitable masks made with canisters to suit different types of fumes, a fireman is not always aware of the exact nature of the fume-laden atmosphere he has to enter; therefore the only type of equipment which will give him complete protection is a self-contained oxygen-breathing apparatus, containing sufficient oxygen either for half an hour or for one hour, such as the "Salvus" or "Proto" sets made by Siebe, Gorman & Co., Ltd. It is essential that every large works should have two sets, preferably of the half-hour type, for the safety of their firemen.

It is necessary to have two sets so that, should a fireman be injured whilst working in a fume-laden atmosphere, another man also equipped with a set will be able to go to his aid.

It should be remembered that General Service gas masks are of no use for other than war gases.

Resuscitators. A first-aid set complete with splints should form part of the mobile equipment of a brigade. Very often firemen have to deal with persons, sometimes amongst their colleagues, who have become gassed through entering a fume- or gas-laden atmosphere containing such dangerous gases as carbon monoxide, and it is advisable to have a resuscitator as part of the fire brigade equipment. This may be a "Novox" set which administers "Dicarbox" gas composed of 95 per cent oxygen and 5 per cent CO_2, or a "Sparklet" resuscitator which uses CO_2 only. (The latter is a very compact set and only costs £3 15s.) The author knows of one case where a man stopped breathing four times on his way to hospital and was resuscitated in the ambulance en route by means of a "Sparklet" set. Both sets are also invaluable in cases of electric shock. A first-aid crew, trained in artificial respiration together with the use of the resuscitation set, should always be available.

General. All gangways, emergency doors, hydrants, etc., should always be kept clear. Where it is necessary to lock outside doors, emergency keys may be kept in a glass box, painted red and fixed on the door, or if panic bolts are fitted, a glass-fronted box can be arranged over the handle. All sprinkler installations should be tested each week to ascertain the standing and running pressures, also the time taken by the alarm bell to operate. The results should be recorded on the test card supplied by the fire insurance company. All fire pumps should also be tested once a week.

CHAPTER IX

FACTORY HEATING

THERE are numerous methods of factory heating, and it is therefore only possible to mention some of the types usually met with in large factories.

Plenum System. Where a plenum system is already installed for ventilation, a heating battery can be installed in front of the fan

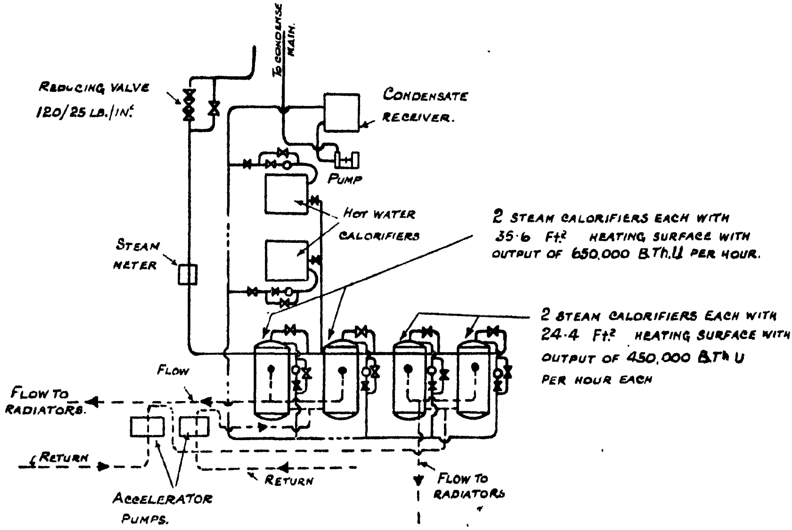


FIG. 170. HOT WATER CALORIFIER HEATING

Heating system comprises 120 radiators with a total heating surface of 4 674 ft.². Cubic capacity of ground and first floors heated by radiators = 345 400 ft.³.

$\frac{345\ 400}{4\ 674}$ = 74 ft.³ to 1 ft.² of radiator heating surface; or, for every 1 000 ft.³ there is 13·5 ft.² of heating surface

as shown in Fig. 138, Chapter VI. With this system it is usual to allow for a 20-minute air change in the building; 1 ft.^{2} of heating surface to each 20 ft.^{3} of air per minute at normal temperature; and 1 000 B.Th.U. per lb. of steam at 60 lb. per in.^{2} pressure. Using these figures as a basis, the average running costs for four plenum heaters dealing with a total of 150 000 ft.^{3} of air per min. is 7s. 4d. per hour, with steam at 1s. 9d. per 1 000 lb., and power at 0·672d. per unit.

Care must be taken to see that the velocity of the air issuing from the ducts is not unduly high, otherwise draughts will be caused. An average figure is 1 100 ft. per min. through the Heater Unit. If there is a tendency for the ducts most remote from the heater to discharge air at a much lower temperature than the ducts near the heater, the cross-sectional area of the more distant outlet ducts should be increased to equalize the general temperature. If the conditioned air seems to be "dead" and the factory stuffy, it may be a sign that the humidity is insufficient.

A certain economy in heating costs can be obtained by recirculation of a portion of the conditioned air, but this should be done with caution. It is impossible to eliminate entirely the stale smell of recirculated air, and the humidity is likely to become excessive if an air-washing plant is incorporated.

Hot-water Heating. In this system the heating is effected by hot-water pipes and radiators, the water being heated in coke- or oil-fired boilers, or in calorifiers heated by low-pressure steam or by electrical heaters. For small factories the coke- or oil-fired boiler may be the best arrangement, but for large works the calorifier is the most economical, especially if low-pressure process steam is available, either as exhaust from process work or from a turbine. Fig. 170 shows a calorifier scheme heated by steam from a back-pressure turbine. It will be noted that 13·5 ft.^{2} of radiating surface are allowed for every 1 000 ft.^{3} of space; this represents a good average figure for light assembly work, etc., and office buildings, and allows for 30° F., difference between the inside and outside temperatures. Table XVII shows the heating surface required for

TABLE XVII

RADIATING SURFACES REQUIRED TO HEAT VARIOUS TYPES OF BUILDINGS

Class of Building	Outside Temperature ° F.	Inside Temperature ° F.	Heating Surface Ft.^{2} per 1 000 Ft.^{3}	
			Hot Water	Low-Pressure Steam
Factory Workshops	30	50	9	5–6
Warehouses and Stores	30	55	11	6–7
Offices, Light Assembly Shops, and Canteens	30	60	15	8–9
Halls and Waiting Rooms	30	60	15	8–9

The above assessments are approximate only. It must be understood that allowances should be made for location, glass surfaces, and for outside walls, etc.

different buildings heated by hot-water and low-pressure steam systems respectively.

It is convenient to arrange for a system of stop valves in the piping, to divide the system into groups of radiators, each group having its own calorifier. This will greatly facilitate repairs, as any individual group can then be isolated. Fig. 171 shows a calorifier house for an office building of 536 000 ft.^{3}

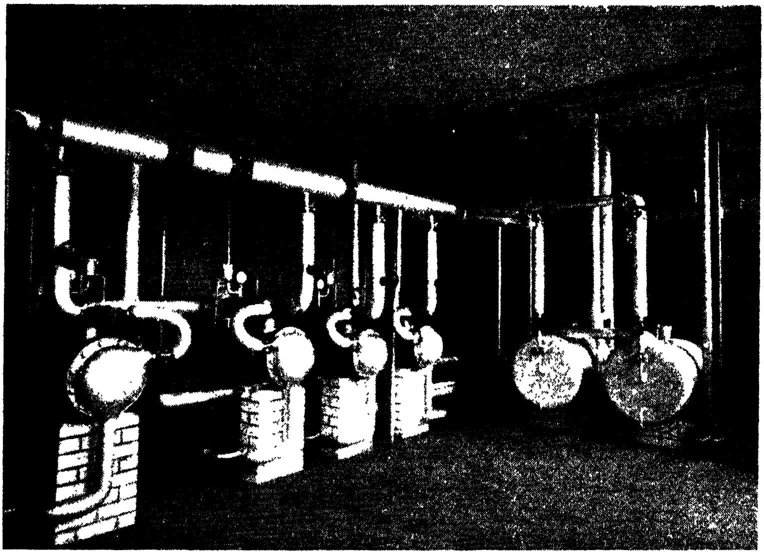


FIG. 171. CALORIFIER HOUSE FOR LARGE OFFICE BUILDING

A new system that has been tried with good results on the continent, and is now in use in this country, is the high-pressure hot-water system. It is a sealed system, and since the water-heating unit (in some cases a water-tube or Lancashire boiler) is worked at a high pressure, a greater temperature can be maintained in the system without actually generating an appreciable amount of steam, although a small percentage of steam can be drawn from the boiler if required. Once the system is filled up with softened water, no trouble is experienced due to scale formation, and, as the leakage is very small, little make-up water is required; distilled water could be used for this purpose if possible.

Electrically Heated Hot-water Systems and Thermal Storage. The heating unit can be either an electrode boiler or an immersion heater unit. Only alternating current can be used for the electrode boiler system of thermal storage; whereas, with the system using

immersion heaters, low-tension direct or alternating current can be employed. As it is not convenient to store electricity in the same way as coal, oil, or gas, the capacity of the electrical supply must be equal to the maximum load, and it is therefore usual to install thermal storage in conjunction with electrical heating. By so doing, the electrical load can be taken off the supply mains during the "off-peak" period, such as early morning, and the heat stored. This arrangement helps to improve the load factor of the supply

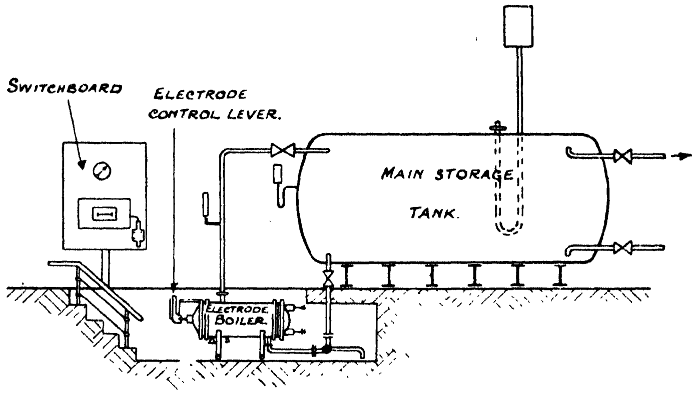


FIG. 172. THERMAL STORAGE HEATING CIRCUIT WITH BOILER BELOW LEVEL OF STORAGE TANK

authority, who will usually quote a low rate of charges for this arrangement. If the flat rate is below ½d. per unit, this scheme is worth consideration, especially for large office buildings.

Fig. 172 shows a typical thermal storage system using an electrode boiler. Another typical installation (at the headquarters of the London Passenger Transport Board) has insulation consisting of 6 in. cork "lags" filled round with crushed slag.

The boiler, operating automatically by time-switches during the "off-peak" period, heats the water in the storage tank, which is efficiently lagged; and the heat is "stored" there. Under atmospheric pressure, water cannot be kept above 212° F., but if the pressure in the system is increased, the temperature at boiling point is, of course, also increased. If, for example, the pressure is raised to 60 lb. per in.^{2}, the maximum storage temperature would be, say, 275° F. Therefore, if the flow temperature through the heating pipes is taken as 120° F., the heat storage per lb. of water would be equivalent to $275 - 120 = 155$ B.Th.U. per lb. With radiators it is usual to allow a flow temperature of 140° F.; and for panel pipe heating in the walls, 120° F. If oil is used instead of water as a

storage medium for immersion heaters it can be heated to 550° F., whilst glycerine can be heated to 500° F.

Immersion Heater Boilers. In this type of boiler, heating is effected by immersion heater units, the elements of which are of nickel-chromium steel, arranged in suitable steel tubes and immersed in a lagged boiler; a battery of these heaters is usually arranged within one boiler so that it is possible to reduce the total number of heaters in service, thus making it easier to regulate the temperature to requirements.

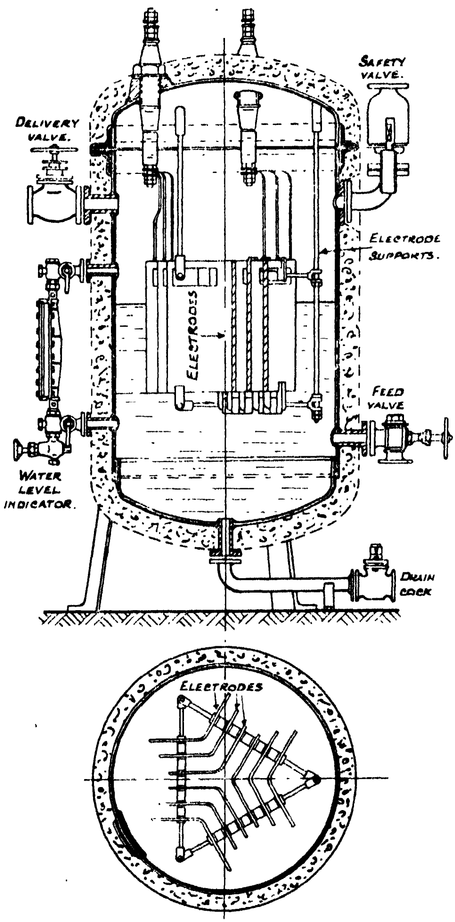


FIG. 173. LOW-TENSION ELECTRODE BOILER (*G.E.C.*)

Electrode Boilers. Fig. 173 shows a section of an electrode boiler. It is composed of three cast electrode plates, suitably mounted on insulated supports and arranged mutually at angles of 120° F., the phase voltage being maintained between each set of plates. These boilers are designed for water of a specific resistance of 200–1 000 ohms per cm.^{3}; it is, therefore, necessary to reduce the resistance of ordinary softened water by adding a soda solution. Efficiencies of 95 to 98 per cent are claimed for this type of boiler.

Heating by Condensate. Where the condensate from steam used for industrial purposes is received back into the condensate tank at or near the boiling point, or where steam has to be exhausted at periods after doing useful work, it is worth considering the circulation of this hot water or steam for factory heating. Fig. 174 shows

a system installed by the author, which is giving very good results. Originally, the condensate was practically boiling at those periods when boilers were on full load (occasioned by additional steam requirements for heating), and trouble was experienced with the feed pumps from time to time. However, by circulating this water through a building of 1 122 000 ft.^{3} capacity the temperature was lowered from 200° F. to 185° F., and the cause of the pump trouble was eliminated; the emission of steam from the condensate tank was reduced to a minimum and, in addition, the factory was heated at little more than the cost of running the circulating pump.

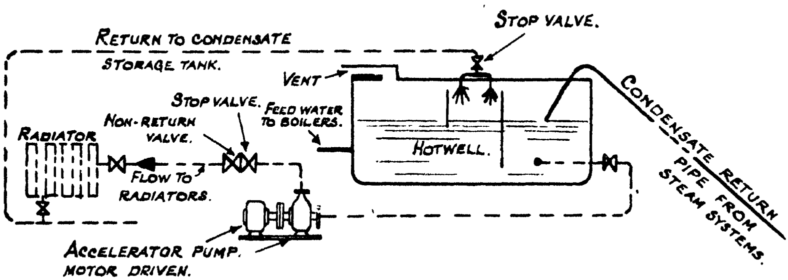


FIG. 174. SYSTEM OF HEATING BY CONDENSATE

Low-pressure Steam Heating. Low-pressure steam heating is perhaps the cheapest to install, as the amount of radiation surface for low-pressure steam is much less than that required for hot water; this fact is illustrated in Table XVII on page 283. This is because the average surface temperature of the pipes in low-pressure steam installations is about 215° F., or 155° F. above room temperature. At this temperature the heat transmission coefficient is increased by 73 per cent, and the total heat transmission by 168 per cent. (The foregoing figures are based on Rietschel-Brabbée, *Heating and Ventilation*, London, 1927.) Again, if the steam is first passed through a back-pressure turbine, the running costs are reduced to a minimum.

Low-pressure steam heating systems usually work on the gravity return system, or by the vapour system.

THE GRAVITY RETURN SYSTEM returns the condensed water to the boiler by gravity. It can be arranged as a single-pipe or two-pipe system; the latter is the better, as in the former, water meets the steam in the risers, causing noise. With the two-pipe system the flow to the radiator consists, naturally, of steam; the return from the radiators consists of condensed water. A water seal is arranged at the radiator outlet. Steam pressures up to 5 lb. per in.^{2} are usual in this system.

THE VAPOUR SYSTEM. This system is generally similar to the gravity two-pipe system except that the pressures are very low; a

pump is installed in the return to assist in excluding all air from the return main, suitable traps being arranged on the radiator outlets. The pump may be arranged to maintain a constant pressure difference between the "flow" and "return" sides.

When laying out steam heating systems of the above types, the pressure allowed should not exceed 5 lb. per in.^{2} gauge, the pressure drop being equal to 1 oz. per 100 ft. of pipe. All pipe diameters

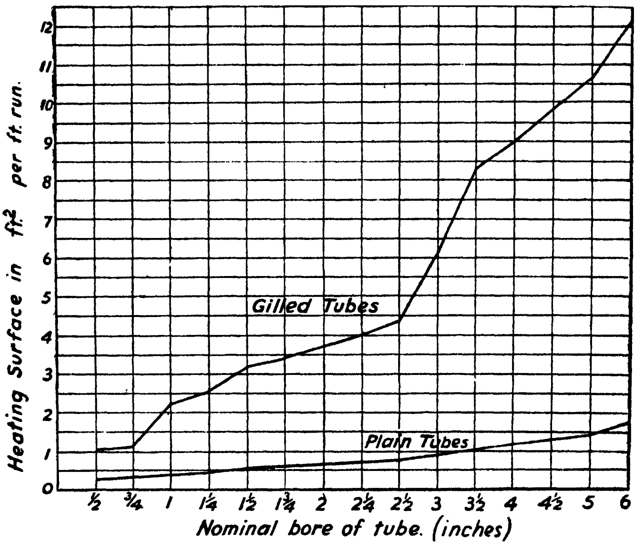


FIG. 175. GRAPH SHOWING THE INCREASED HEATING SURFACE OBTAINED BY GILLING

(Tubes and gills as tabulated on facing page)

(*G. A. Harvey & Co., Ltd.*)

should be proportioned to give a uniform flow through the flow and return systems; in other words, a uniform drop in pressure throughout the system should be aimed at. A gradual fall of about ½ in. in 10 ft. should be allowed. Where the steam supply is taken from a high-pressure main some distance from the boilers, the return can be pumped back by a condensate pump, similar to the type shown in Fig. 49, Chapter II, page 77.

Medium-pressure Heating. For factory buildings, where steam at a pressure of from 15–25 lb. per in.^{2} is used for process work, it may be advisable to tap the process steam main in order to supply the heating system, the condensate being returned through steam traps to a common condensed return main, thus eliminating separate supply mains. At one works, some acres of north-light shops are using this system, which is giving very satisfactory results. Piping of a standard diameter of 3 in. is used, gilled pipes

being added to make up the required heating surface. Fig. 175 shows the increased radiation surface for different diameters of gilled pipes, as compared with plain pipes of the same diameter.

TABLE XVIII

HEATING SERVICE OF GILLED TUBES

Tube		Thickness of Gills I.W.G.	Dia. over Gills (in.)	Pitch of Gills (in.)	Weigh in lb. per ft.	Heating Surface in ft.^{2} per ft. run	
Nominal Bore (in.)	Outside Diameter (in.)					Tube	Gills
$\frac{1}{2}$	$\frac{27}{32}$	20	$1\frac{13}{16}$	$\frac{1}{2}$	1·70 1·623 1·55	0·23	0·785
$\frac{3}{4}$	$1\frac{1}{16}$	20	$2\frac{1}{16}$	$\frac{1}{2}$	2·20 2·065 1·96	·28	·91
1	$1\frac{11}{32}$	20	$2\frac{13}{16}$	$\frac{1}{2}$	3·70 3·53 3·35	·36	1·87
$1\frac{1}{4}$	$1\frac{11}{16}$	20	$3\frac{1}{8}$	$\frac{1}{2}$	4·73 4·50 4·27	·442	2·10
$1\frac{1}{2}$	$1\frac{29}{32}$	19	$3\frac{7}{8}$	$\frac{5}{8}$	6·40 6·137 5·873	·51	2·65
$1\frac{3}{4}$	$2\frac{5}{32}$	19	$4\frac{1}{8}$	$\frac{5}{8}$	7·02 6·711 6·407	·56	2·83
2	$2\frac{3}{8}$	19	$4\frac{5}{16}$	$\frac{5}{8}$	7·57 7·23 6·88	·623	3·10
$2\frac{1}{4}$	$2\frac{5}{8}$	19	$4\frac{9}{16}$	$\frac{5}{8}$	8·80 8·33 7·955	·70	3·30
$2\frac{1}{2}$	3	19	$4\frac{7}{8}$	$\frac{5}{8}$	10·0 9·46 9·12	·80	3·60
3	$3\frac{1}{2}$	19	$5\frac{7}{8}$	$\frac{5}{8}$	12·7 12·05 11·53	·92	5·25
$3\frac{1}{2}$	4	19	$6\frac{7}{8}$	$\frac{5}{8}$	16·2 15·45 14·84	1·05	7·30
4	$4\frac{1}{2}$	19	$7\frac{3}{8}$	$\frac{5}{8}$	18·25 17·4 16·7	1·18	7·86
$4\frac{1}{2}$	5	19	$7\frac{7}{8}$	$\frac{5}{8}$	20·0 19·04 18·26	1·31	8·50
5	$5\frac{1}{2}$	19	$8\frac{3}{8}$	$\frac{5}{8}$	21·7 20·63 19·77	1·44	9·20
6	$6\frac{1}{2}$	19	$9\frac{3}{8}$	$\frac{5}{8}$	25·1 23·8 22·8	1·70	10·45

The old design of "Harco" crinkled gill piping has recently been superseded by a type, made by the same company, in which the gills are tapered and shrunk on when hot. Not only does this avoid the tendency to rust at the root of the gill, but the efficiency is between 20 and 25 per cent greater than that obtained with the

old type. The heat emission is approximately 1·25 to 1·3 B.Th.U. per ft.^{2} per degree F. temperature difference per hour.

The quantity of heating surface can be found from Table XVIII. When such pipes are used as heater batteries, reasonably accurate results will be achieved by taking as a basis of calculation a figure of 4½ B.Th.U. per ft.^{2} per degree F. temperature difference per hour, for an air velocity of 350 ft. per min. For an air velocity of 2 000 ft. per min. the corresponding figure is 9 B.Th.U.

Painting of Pipes. Heating pipes should not be covered with aluminium paint. Whilst a little advantage may be gained in reflected light, the efficiency of the pipes as radiators is greatly reduced. A report* of the experiments carried out by Ezer Griffiths, D.Sc., and A. H. Davis, M.Sc., gives the following heat emission from radiators painted different colours—

Colour	Ratio to Dead Black
Dead black	1·0
Black paint	1·0
Black enamel	1·0
Dark green paint	1·0
White paint	1·0
Aluminium paint—1 coat	0·7
Aluminium paint—2 coats	0·5–0·7

Where different colours are required to distinguish between hot-water and low-pressure steam systems, only the pipe flanges or sockets need be painted in these colours, e.g. aluminium sockets and flanges for low-pressure, and green for hot-water systems.

Steam Unit Heaters. In this system, heaters arranged at suitable distances and heights blow the heated air wherever it is required. The unit is composed of a motor-driven fan, which blows the air through a heating battery fitted with deflectors to force the heated air down. A typical unit, with the method of connection, is shown in Fig. 176. Both steam and condensate connections can be made to common mains for a battery of heaters. Installation costs are low, as no heating pipes and radiators are necessary. The heat is driven down from above to the breathing level and the units can be arranged to give a good circulation of the air which might otherwise contain cold pockets. Units may be suspended from the roofs at heights varying from 8 to 14 ft. from floor level, depending on the size of the heater. Pressures from 2 to 100 lb. per in.^{2} gauge pressure may be used, and the capacity of the units may vary from 16 500 to

* Special Report No. 9 of the Food Investigation Board to the Department of Scientific and Industrial Research, published in 1922 by H.M. Stationery Office. The tests were carried out on two 26 in., 10-section, 4-tube cast-iron radiators.

600 000 B.Th.U. per hour output. The "Trane" unit is one of the best-known heaters of this type.

USEFUL HEATING INFORMATION

To find the amount of radiation required for a building, the temperature likely to occur under the worst outside conditions must first be decided, the outside temperature being taken as the average minimum temperature over a number of years $-10°$ F. In

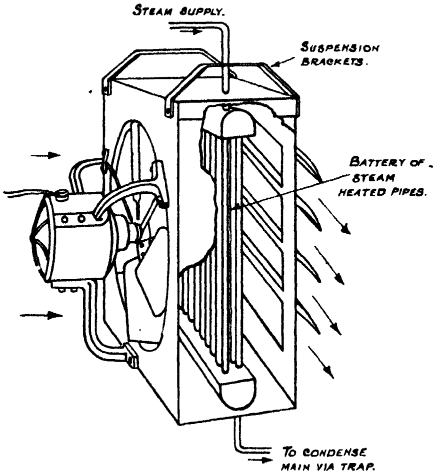


FIG. 176. UNIT HEATER AND CONNECTIONS

this country the resulting figure usually amounts to about 30° F. Harding and Willard give the following formula—

$$H = (1{\cdot}2\,P + \tfrac{1}{4}\,W + G)\,(t - t_1)$$

where H = Heat loss in B.Th.U.
G = Glass surface in ft.^{2}
W = Wall surface in ft.^{2}
P = Perimeter of windows in ft.
t = Desired temperature in ° F.
t_1 = Outside temperature in ° F.

For an approximation, the figures given on page 283 in Table XVII will be found fairly accurate.

Shop Temperature Records. The maximum and minimum temperatures in each shop should be recorded twice daily, using a special thermometer, such as that manufactured by Messrs. Negretti & Zambra. Readings should be recorded on a sheet provided for the purpose and sent to the Works Engineer's office each day.

Heat Units. The British Thermal Unit (B.Th.U.) is the standard unit of heat in English speaking countries and is the quantity of heat required to raise 1 lb. of water 1° F. at 60° F. The heat needed to raise 1 lb. of air through any desired number of degrees F. is equal to 0·2379 times the heat required to raise 1 lb. of water through the same number of degrees. The (major) calorie is the unit in France and Germany and is the quantity of heat required to raise 1 kg. (2·20 lbs.) of water 1° C. To convert B.Th.U. to calories, multiply by 0·252, and to convert calories to B.Th.U., multiply by 3·968. At atmospheric pressure 1 lb. of steam will raise 1 700 ft.^{3} of air from 30° F. to 60° F. 1 kW = 3 415 B.Th.U. per hr.

The heating power of a boiler is sometimes given as the heating power in square feet radiation surface × 144. For hot water it is usual to allow 180 B.Th.U. for 1 ft.^{2} of radiation surface. In the case of steam, the heating power depends on pressure and temperature, but for low-pressure systems it may be taken as 240 B.Th.U. for 1 ft.^{2} of radiation surface.

CHAPTER X

FACTORY BUILDINGS

Of late years, it is satisfying to note, more thought has been given to the appearance of factory buildings, and nowadays, in the case of new factories on the outskirts of large towns or cities, care is taken to provide a good façade. Any firm contemplating a new factory should bear this point in mind. Whilst the works may be in a field to-day, there is every possibility of the surrounding area becoming residential to-morrow. Apart from this, there is the psychological effect on the worker or the potential customer who may come to the works.

Site. When choosing a site, a number of things relevant to the requirements of the specific manufacture have to be taken into consideration; but railway, and, if possible, canal facilities for transporting heavy materials, fuel, etc., must be considered. Water, gas, and other services will also have their bearing on the choosing of a site, likewise the cost of land, drainage, and the possibility of extension. It is therefore not possible to lay down any hard and fast rules.

Types of Buildings. Factory buildings can be classified under three main headings: single-story, multi-story, and combined single- and multi-story. Whilst the determining factors will be the class of manufacture, the size of the factory, and the ground available for extensions, besides the many points peculiar to a particular factory, the following paragraphs will give some idea of the merits and demerits of each particular type.

Single-story

In this country—in fact, in the whole of Europe—the north-light factory has been looked upon as the standard type of a single-story construction. In America, buildings of the "Monitor" or similar type of construction, with east and west lighting, are considered far ahead of the north-light type, on account of better ventilation and lighting. In such buildings the sun's rays are deflected by the use of ribbed glass. A section of this type is shown in Fig. 177. Compared with the north-light type, however, the cost is considerably higher.

The "saw-tooth" or north-light factory is usually arranged in bays 20 ft. or 30 ft. wide; for machine shops the latter width will allow better spacing of the machines when they are of medium or small sizes. Where it is essential to eliminate stanchions as far as possible, two or more bays may be carried between stanchions;

Fig. 178 shows three methods of doing this. The clear height is usually between 12 ft. and 14 ft.

When plenty of ground is available for expansion, the single-story north-light construction is the cheapest. The points in favour are briefly as follows—

Good and even distribution of lighting without glare through the north lights.

Better layout of lines of production.

Easier transport, as electric or other trucks can be used to transport materials from one department to another, thus avoiding

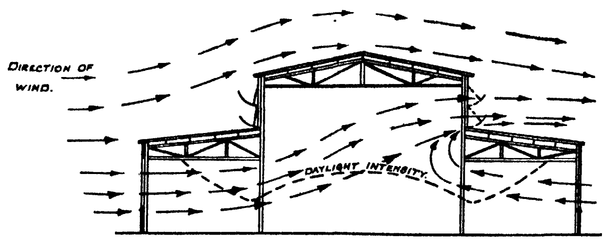


FIG. 177. MONITOR ROOF, SHOWING DIRECTION OF VENTILATION AND LIGHT

unloading at lifts or the installation of lifts large enough to carry transport trucks.

Facilities for unloading raw materials at any required position (this also applies to the dispatch of finished articles).

Lessened fire risks, as a fire in a single-story factory can be more easily isolated from the rest of the building. With the multi-story building there is always the possibility of the fire spreading to the floors above; conversely, if the fire is on the top floors, the water damage is always greater, as the water finds its way to the floors below.

The single-story building with a gallery all round is frequently favoured in cases where a number of small components, which can be manufactured in the gallery, are assembled in the central space at ground floor level. Where none of the components manufactured in the gallery is particularly heavy, the difficulties of arranging for the galleries to be of sufficiently robust construction are much simplified.

An incidental advantage in single-story construction is that it is easier to arrange for an office, glazed on all four sides, and raised slightly above floor level, to give supervision of the entire building.

Whilst there are a number of advantages, there are also a number of disadvantages in the single-story building. The roof maintenance, slates, glass, cleaning, and repair of gutters, etc., will be four times greater than a four-story building of equal capacity; and drains

must be correspondingly large to cope with the rainwater at storm periods. Ventilation, too, must not be overlooked ; it is very difficult to ventilate a large single-story factory efficiently, especially during hot weather, owing to the proportionately large area of roof, which

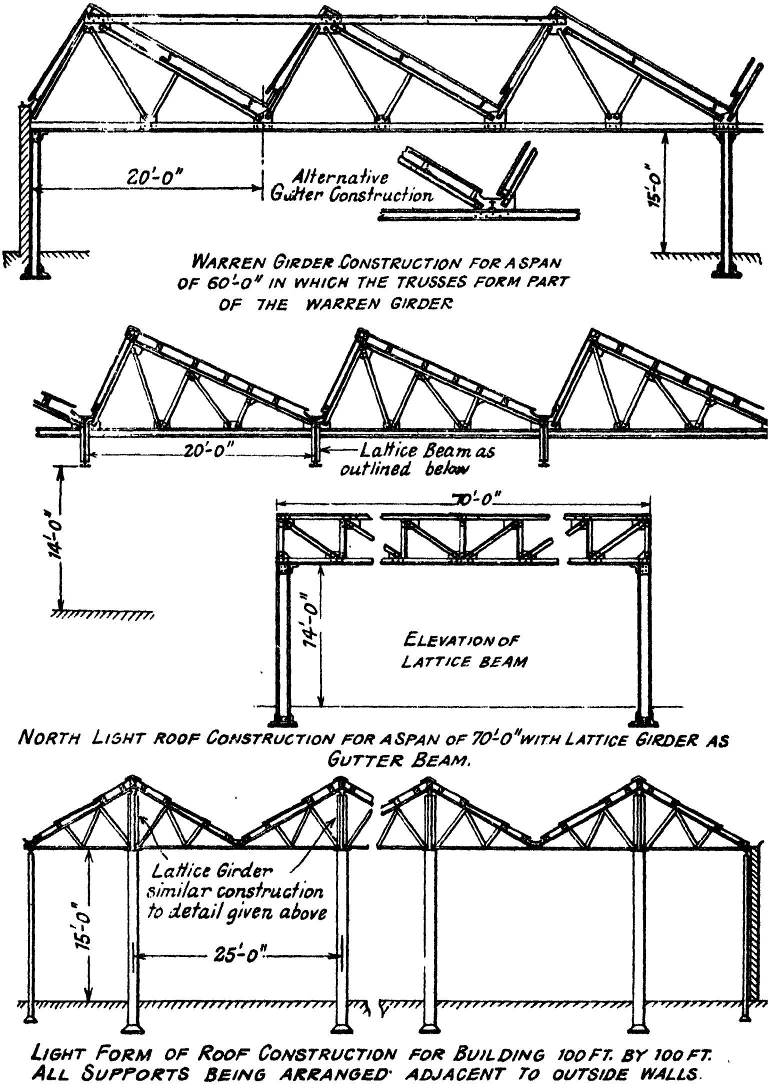


FIG. 178. TYPES OF ROOF CONSTRUCTION FOR LARGE SPANS

holds the heat, and owing to the distance from outside windows of the interior parts of the building.

Services are another drawback, as all steam or other service pipes and mains, also electric cables, have to be considerably longer; this increases the pressure drop, voltage drop, etc., unless, of course, the boiler plant and power supply can be situated in the centre of the works, which is often impracticable.

Construction. All manufacturing shops should be of one standard construction throughout to facilitate change-overs of overhead shafting brackets, motors, etc. All steelwork should be free from the brickwork, to allow of expansion and contraction due to the variation in summer and winter temperatures; otherwise trouble will always be experienced at piers, due to cracked brickwork.

Foundations for stanchion bases will depend, of course, on the nature of the ground, but the floor concrete should be of an average thickness of 6 in., reinforced with No. 9 British Reinforced Concrete or similar material, the surface being kept clean to allow of a screeding to suit the type of floor decided upon.

Roofing. Slated roofs, when slated on single match boarding, should have a layer of felt between the match boarding and the slating slats; this serves both as heat insulation and, what is more important, it prevents dust from percolating through the joints of the match boarding, which shrinks as it becomes thoroughly dried out. One of the lightest forms of roof construction is asbestos slates, laid in this way.

Whilst slates were at one time recognized as the usual covering for factory roofs, to-day protected steel sheets are becoming more popular, due to the very small amount of maintenance they need, whereas slates require periodical repairs and attention. "Robertson Protected Metal" ("R.P.M.") is one of the best-known types of steel sheet covering.

The "R.P.M." roof consists of steel sheets with a coating of asphalt, followed by an asbestos felt coating, the whole being sealed in an envelope of hard asbestos. It is made in corrugated or "mansard" shape in suitable lengths and the net covering width is usually 21 in. to 24 in., depending on the length of sheet. Knowledge of the weight of these sheets is useful in designing an "R.P.M." roof; the following tables give the weight per 100 linear feet, allowing for standard widths to suit the different gauges. "Linear feet" is taken to mean sheets placed end on end.

Gauge	Net Weight (lb. per 100 linear feet when painted black or aluminium)
No. 26	333
No. 24	386
No. 22	454
No. 20	538

Add 25 lb. per 100 linear feet when painted maroon colour.

The corrugations can be arranged as $10\frac{1}{2}$ corrugations of $2\frac{5}{8}$ in. pitch, or as 8 corrugations of 3 in. pitch, or "mansard." The weights are the same for each shape of the same gauge.

"R.P.M." PURLIN SPACINGS. Where the rise is 4 in. or more in 12 in. the following purlin spacing may be used—

Gauge	Spacing: $10\frac{1}{2}$ of $2\frac{5}{8}$ in. pitch		Spacing: 8 of 3 in. pitch, or "mansard"	
	ft.	in.	ft.	in.
No. 26 up to .	3	9	4	3
No. 24 up to .	4	9	5	6
No. 22 up to .	5	9	6	6
No. 20 up to .	6	6	7	3

At one factory with about 97 000 ft.^{2} of this roofing—some of it over ten years old—the maintenance has been practically nil, the only repairs being made where men had been working on the roof—say, fitting cowls or vents—and then it was only necessary to coat places where the surface had been damaged, with a special bituminous compound.

In the case of a chemical works, where there is a continual menace to steelwork from corrosive fumes, it is wise to avoid steel as a material for purlins, timber being preferable in many cases.

CORRUGATED ASBESTOS SHEETING is another form of roof covering, but unless adequate precautions are taken it is very dangerous for men working on the roofs, as the sheets have a tendency to become brittle with age. The author has known one serious accident due to a man falling through a roof of this type whilst cleaning gutters.

A standard form of north-light factory is shown in Fig. 179. "R.P.M." roofing is used, clipped straight on to the purlins, the underside being covered with "Paramount" boarding $\frac{3}{8}$ in. thick, nailed to rough wooden struts clamped to steelwork, which forms a good air seal, thereby greatly increasing the insulation of the roof and helping to keep the factory temperature normal whatever the outside condition. "R.P.M." has one disadvantage: in the event of a bad fire the asphalt coating tends to melt and catch alight, thus feeding the fire.

GLAZING. Rough-cast roofing glass $\frac{1}{4}$ in. thick should be used, and where there are continuous opening lights or a number of smaller opening lights, the glass should be wired. Patent glazing bars should be used. There is a number of very good makes on the market, such as the Mellowes "Eclipse" glazing bar, an advantage of which is the absence of asbestos string packing, which has a tendency to deteriorate with age. A section of one of these bars is shown in Fig. 180.

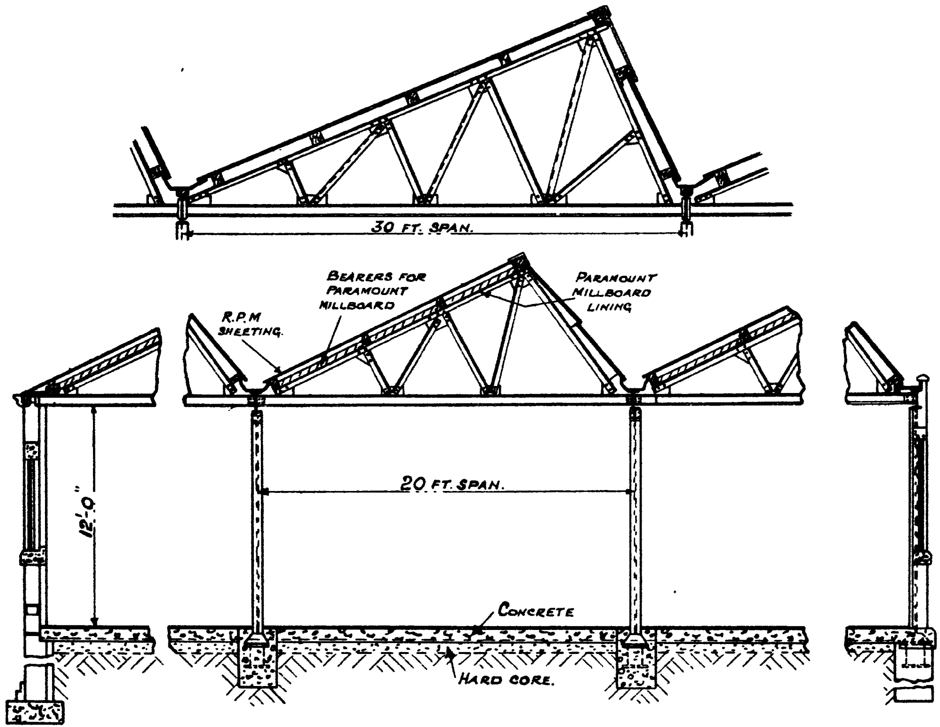


FIG. 179. NORTH-LIGHT ROOF CONSTRUCTIONS

In heat-treatment shops the glass is usually painted green. This painting can be dispensed with by using, for example, Pilkington's green non-actinic roofing glass; better light is given in the shop, and from actual experience the author can vouch for the fact that it is then easier to judge heat colours than with the old semi-darkened shop. This glass can be obtained either wired or unwired, and the light absorption is only 20 per cent.

Much time and expense can be saved by endeavouring to reduce the panes in the factory to a few standard sizes, the larger preferably being multiples of the smaller unit. A stock of glass sheeting should

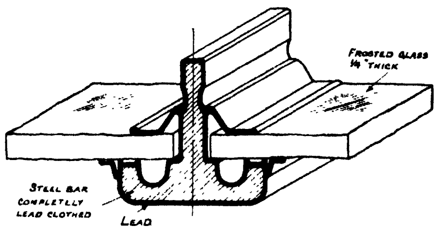


FIG. 180. SECTION OF GLAZING BAR

be kept at the works, and panes cut to the standard sizes should be stored so that replacements of broken panes can be made without delay.

Proportions of Windows and Width of Rooms. These proportions depend on the arrangement of the windows. If the room is lighted along one side only, the width may be made one and three-quarter times the distance from the floor to the top of the window, assuming that one-half of the external wall surface is window space, and that all windows extend upwards so that their tops are close to the ceiling, the lower edge being about 3 ft. from floor level. If the room is lighted by such windows along two opposite sides, the width can be made four times the distance between the floor and the top of the windows. For these proportions the width of the sashes should be at least seven times the width of the piers between the windows. Ceiling and walls are assumed to be painted in light shades, and in clean condition. It will be realized that a good deal of light can be blocked out if another building is adjoining, and allowance should be made for this factor. Here, again, it must be remembered that much depends on the nature of the work; the "dark" side of a shop may be used as a store.

Opening Lights. Ventilation in a large single-story factory is very difficult. Whatever mechanical measures are taken to ensure good ventilation, continuous opening lights and windows—which are usually steel casement, centre-pivoted—in all walls will give much better results than any mechanical means, providing, of course,

it is not necessary to control the humidity of the air inside the factory.

These continuous opening lights can be of any length up to 100 ft. or even 200 ft. Hand operation is suitable for lengths up to 80 ft., but for greater lengths a motor-driven unit should be used. Fig. 181 shows the construction and operation. Wired glass should always be used.

Continuous opening lights are, of course, the ideal method, but as the cost is practically double that of ordinary glazing,

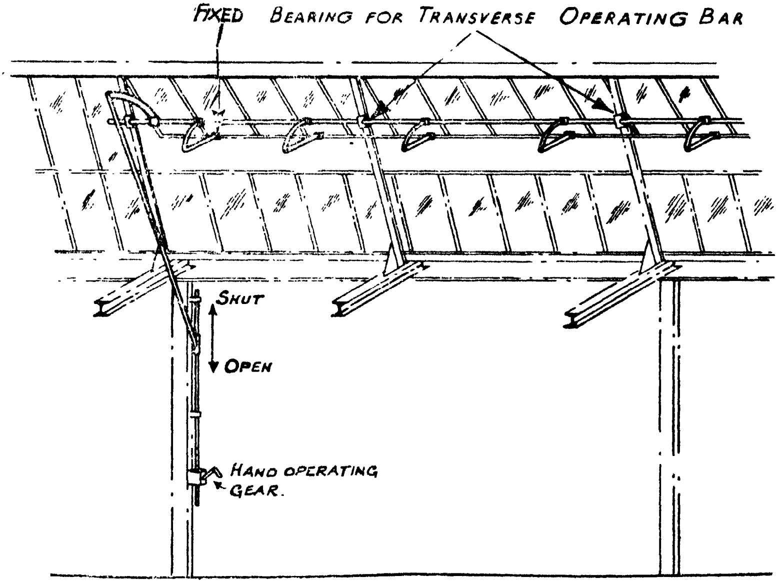


FIG. 181. CONTINUOUS OPENING LIGHTS WITH HAND OPERATION

some type of fixed ventilator near the apex of the roof is a cheaper method. The author has found the "R.P.M." ventilator one of the most efficient. It does not look pretty, but it is effective, and the ventilator is made of a covered steel similar to "R.P.M." sheeting, so the maintenance is practically nil.

Gutters are usually of cast iron, steel, or asphalt. The use of cast iron is not recommended for valley gutters, as the expansion due to change of temperature causes movement and leakages at the joints. If they are too tightly bolted together, cast iron gutters are also inclined to crack.

The steel gutter is a very good type, but if the air in the shop is inclined to be humid, trouble will be experienced due to condensation,

the condensed water dripping into the shop. (A heating pipe below the gutter will usually cure this.)

Asphalt gutters, provided the timber foundation is rigid, give very little trouble, and are perhaps the safest in cases where condensation will cause trouble with components under manufacture. Details of steel and asphalt gutters are given in Fig. 182.

Downpipes. For a construction such as that shown in Fig. 179, downpipes of 4 in. diameter should be spaced at 60 ft. centres, with emergency overflows at outside walls (as shown in the gutter details). All outlets from gutters into downpipes should have "balloon" wire cages to prevent leaves and dirt collected in the gutters from getting into the downpipes.

Drains. In almost every district in the country the local authorities require that drains for sewage shall be quite separate from those for rain-water. No empirical formula can be taken as to storm water drain sizes; everything depends on the number of outlets, their distance away from the building, and the speed with which the water can get away. Each job must, therefore, be considered on its merits. Rainfall statistics will usually only give the amount of rainfall per day, whereas the duration and heaviness of a storm, i.e. amount of water falling over a given period, and its intensity must be known to allow of emergency measures being taken to deal with extra heavy downpours. The "Hyetograph" with daily recording chart is worth installing if trouble has been experienced; the size of emergency or overflow drains can then be decided on from the readings taken over a period. These drains should be connected to inspection manholes—which should be spaced at about 120 ft. intervals to allow of rodding and keeping the drains clear—and arranged at such a height that they only come into operation when the water flows back up the manhole. These drains should have an open outlet to a brook or ditch. Inspection covers should be fitted at all connections to down-spouts; these covers can be screwed down. The fall allowed on storm water drains is usually 1 in 70 for 6 in. diameter pipes and 1 in 100 for 9 in. diameter pipes, but this again depends on conditions.

The position of the pipe will help to decide whether it should be of iron or salt-glazed earthenware. The former should be used where the drains pass under buildings. Iron drains are more expensive than earthenware, but the extra expense is offset by the advantage of greater strength. The internal surfaces of iron pipes should be treated with some anti-corrosion solution before the pipes are laid. Spun cast iron pipes are much stronger and more reliable than those cast vertically.

Cast iron inspection covers should be provided wherever a junction or bend occurs, and expansion joints fitted at any point where a hot liquid discharges into the drain. Manholes should be placed at each point where the direction changes.

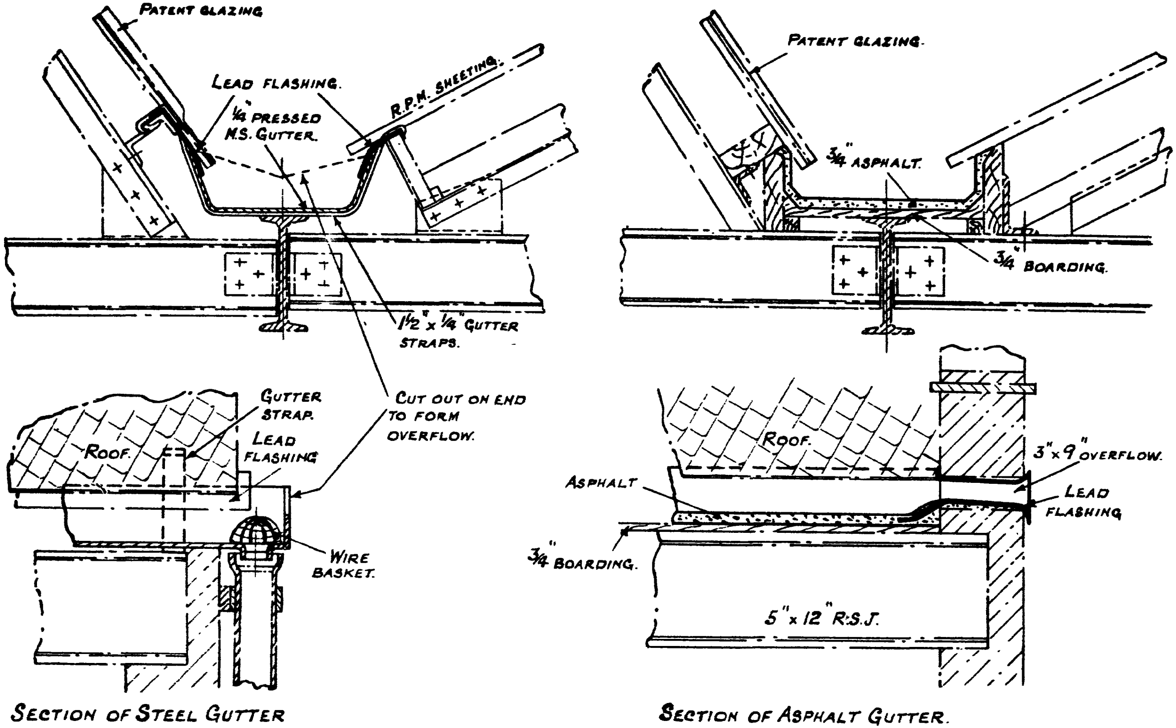


Fig. 182. Constructional Details of Gutters

The triple intercepting chamber for oils shown in Fig. 183 is insisted upon by the London County Council as a fitting where a garage is part of the factory premises. Similar chambers should be installed in all drains from buildings from which oils and waste oily products may be discharged.

Details of gullies, inspection chambers, and drain connections are given in Fig. 183.

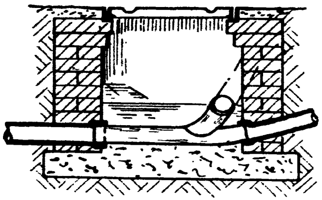
Floors. Whilst there are many types of flooring to suit various conditions, everything depends on the class of work and the usage the floor will get.

For machine shops, or medium and heavy assembly work, the composite magnesite floor, such as "Jaconello," will give good service, providing the concrete sub-floor is perfectly clean. It can be laid on a cement screeding of, say, $\frac{3}{4}$ in. to 1 in. thickness, or laid direct on the concrete in two coats, i.e. a screed and a finishing coat. Cleanliness of the concrete is essential if this floor is to give good service and not crack or "pick up." A good scheme is to fit hardwood lining division strips, say $\frac{1}{4}$ in. wide, in 10 ft. squares; then if part of the floor should crack, it can be chipped up without disturbing the next section. This arrangement has been found very satisfactory. The magnesite floor is perhaps the cheapest form of good flooring when properly laid.

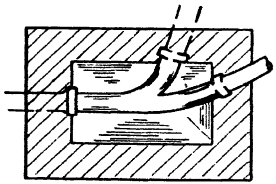
"Magnesite" floors have as a basis magnesium oxychloride, formed by a chemical combination of magnesia and magnesium chloride, which together form a cement-like compound. Such floors are sensitive to dampness, but this can be overcome by using oil-bound magnesite in the composition.

The great objection to all floors of this type in machine and fitting shops, namely, that they are cold to the feet, can be overcome to some extent by providing a standing or "duck" board at each machine or vice. In view of the danger of tripping over such boards, however, it is necessary to see that the machinery is adequately guarded.

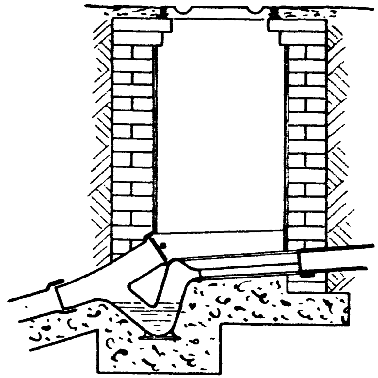
Wood Block Floors. For light assembly shop or office floors the wood block is the ideal floor, providing it is kept dry. This floor is laid on a good cement screeding, which is coated with a bituminous compound, the blocks being interlocking, usually tongued and grooved. A good size of block is $8\frac{3}{4}$ in. × $2\frac{3}{4}$ in. × 1 in. The choice of the class of wood is very important. Though a soft wood may appear to be cheaper, it is well worth while spending a little extra and getting a good hardwood. A good grade of pitch pine would seem to be adequate for office floors, but unless the furniture is rearranged occasionally the floor will wear badly through the scraping of feet at the places where people sit or where a chair is constantly being moved slightly. Various types of oak—Tasmanian, Japanese, Austrian, or Jarrah—will also give good service, Jarrah perhaps having the closest grain; but even with these floors an



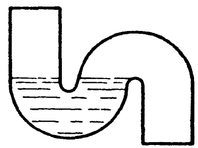
CROSS SECTION.



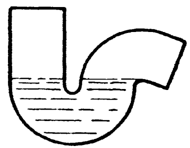
PLAN
INSPECTION CHAMBER.



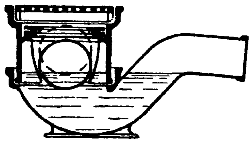
DISCONNECTING CHAMBER.



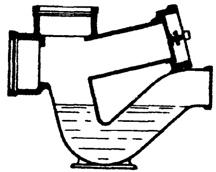
"S" TYPE TRAP.



"P" TYPE TRAP.



ANTI-FLOODING BALL VALVE
GULLY & TRAP.



INTERCEPTING TRAP WITH
CLEARING ARM.

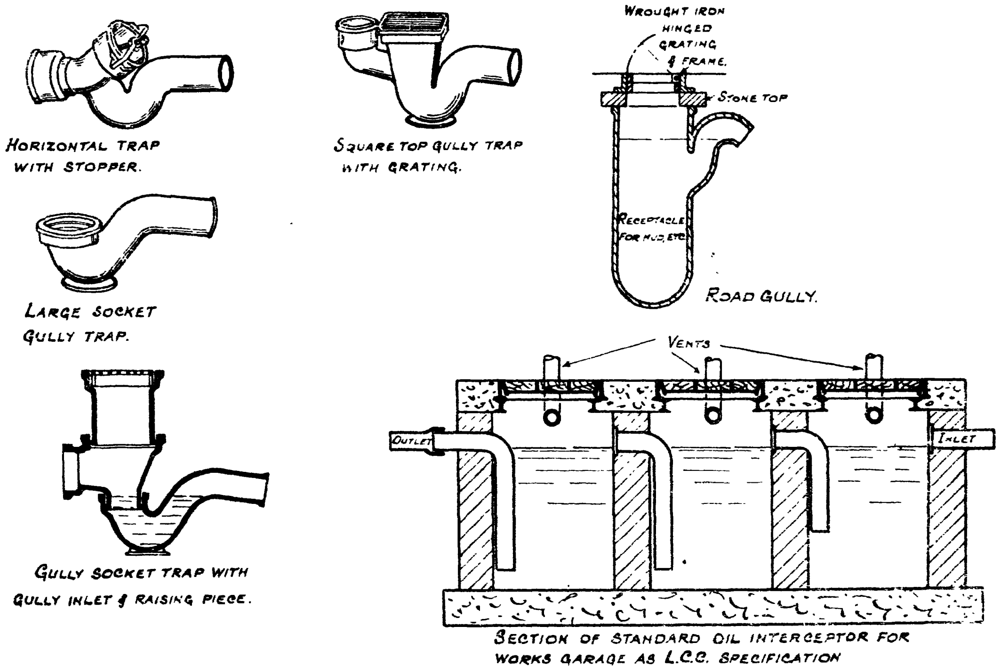


FIG. 183. DRAIN AND MANHOLE DETAILS

occasional block will roughen up. The most satisfactory type of block is the maple, especially if used for assembly shops where there is comparatively heavy wear. To ensure a good maple floor, the following conditions must be fulfilled: the foundation must be good, dampness must be excluded, the maple must be uniformly and continuously supported, and provision must be made for expansion.

Even with wood block flooring it is advisable to lay the floor in sections; e.g. down each bay, with a double row of blocks placed end to end between each section. Thus if one section should lift, due to expansion, which may be caused by water leakage over the floor, the damage will be sectionalized. The joints between the wood blocks themselves should be sufficiently large to allow for expansion. For this purpose it is often a good plan to fit a cork fillet around the outside edges.

For heavy duty, as in large press shops, heat-treatment shops, etc., where hot articles may be placed on the floor, steel-clad flags are recommended. "Stelcon" flags make a good floor. These are composed of concrete with a top wearing surface, of about $\frac{3}{8}$ in. thickness, of steel chippings, the whole flag being manufactured under a pressure of 250 tons per ft.^{2}; flags are made 12 in. square $\times$ $1\frac{1}{2}$ in. or 2 in. thick. Whilst they will withstand a considerable amount of heat, it is advisable, in a heat-treatment shop, to have cast iron grids or plates let in at different points where red-hot pots can be left to cool. The "Stelcon" flags should be laid on concrete of not less than 4 in. thickness, the maximum thickness depending on the ground; they are grouted in with a thin cement grout, composed of 5 lb. Portland cement to 2 gal. of water. The bedding is composed of 1 part cement to 3 parts of clean sharp sand. These flags are impervious to water.

Several types of flooring have been tried in fettling shops, following the Government requirements that it must be possible to sweep the floors of such shops clean, in order to prevent silicosis. It seems probable that the best floor is simply earth mixed with clay, since iron oxide gets into the surface and forms a firm floor which can be brushed without difficulty. Floors for battery rooms are mentioned on page 321.

Maintenance of Wood Block Floors. Where polished wood block floors are laid, such as in office buildings, they should be polished at least twice a week during the first six weeks. When a new floor is dressed, the pores of the blocks are open and the wood therefore absorbs the polish which must be fed into the blocks until a saturation point is reached.

A thin polish must be used, made up from a good proprietary brand of polish or pure beeswax polish, thinned down with turpentine to the consistency of cream. After the six-week period, floors may be polished in the normal way, say once a week.

Where a polished floor becomes dirty, it should be scrubbed with turpentine with a flat scrubbing brush. As the dirt comes up, it should be wiped off with clean newspaper, which should be burnt

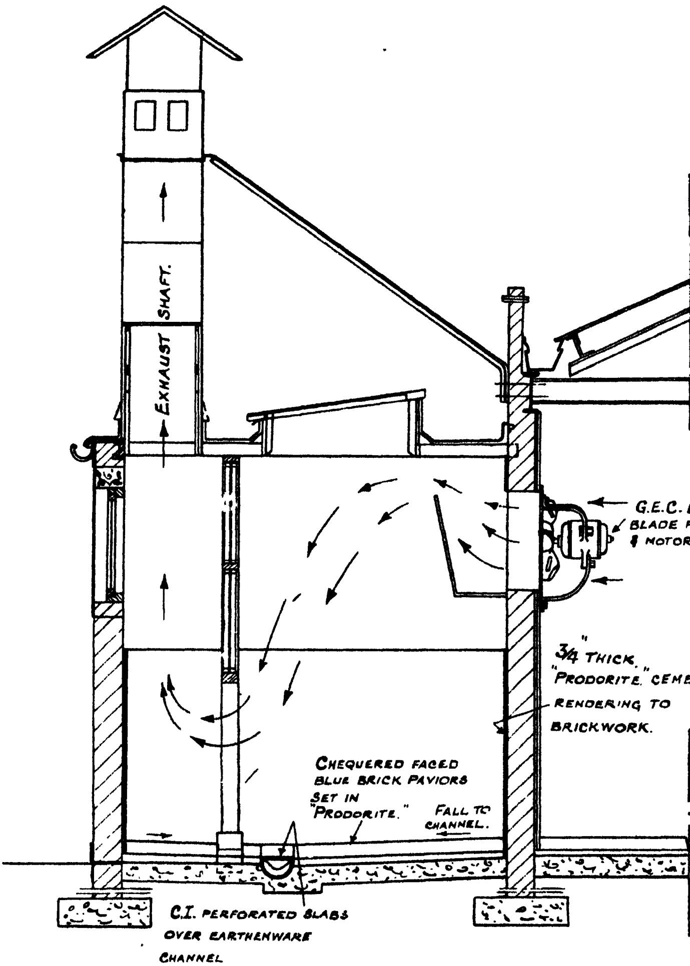


FIG. 184. SHOWING USE OF "PRODORITE" IN DIPPING SHED

after use. Polishing should be carried out as before. If the floor is very bad it may be necessary to scour it with steel wool and turpentine.

Acid-resisting Floors. For acid-dipping or similar shops an acid-resisting floor is necessary, as concrete will gradually disintegrate

and crumble away. Asphalt is sometimes used, but its life is not very long as, due to the formation of small cracks, the acid finds its way to the concrete below. Blue paviors set in sulphur or paraffin wax are also used, but the acid eventually finds its way through. A good construction is a concrete foundation, say 6 in. thick, coated with "Prodorite," with chequered face; or blue brick paviors set in the same material; or Duckett's acid-resisting bricks. A typical construction with "Prodorite" is shown in Fig. 184. This section also shows the method of ventilation.

"Prodorite" is similar to ordinary cement concrete in that it is composed of a graded stone aggregate held together by a bonding material of acid-resisting properties. The aggregate is a highly siliceous quartzite selected for its inertness to hot hydrochloric acid, the binder being a specially distilled coal-tar pitch. It is non-plastic up to 70°–80° C., and for some purposes it can be specially

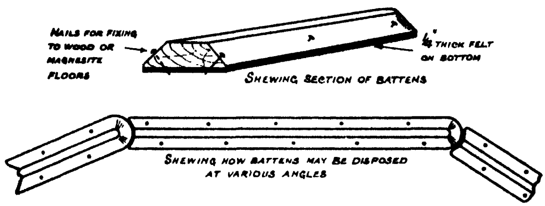


FIG. 185. USEFUL FORM OF TIMBER BATTEN IN CASE OF FLOODS

made to withstand 100° C. It is very strong when set and will withstand a crushing strength of 6 000 lb. per in.^{2} Its mean thermal coefficient of linear expansion, determined between the temperatures of 0° C. and 37° C., is 0·0000181 per degree C. Its weight is approximately 146 lb. per ft.^{3}. It may also be bought pre-cast in various shapes. Acid-resisting floors should always be laid with a fall to gullies in order that they may then be washed down frequently.

With all single-story factory floors, due to their large areas, it is advisable to arrange channels covered with chequered plates or cast iron grids, in order to sectionalize water drainage from fire or flood, and these should have a gradual fall to the storm water manhole. It is also advisable to have an ample supply of sawdust available. Battens, as shown in Fig. 185, are very useful, and a truck full should always be kept ready for rushing to an affected area to confine the water to a minimum area; they are easily nailed to the floor (magnesite or wood) without damage, and then with the aid of rubber squeegees, the water can easily be got away.

If a single-story factory with a gallery is decided upon, it is a good plan to fix a "fillet" all round the edge at the "nose" of the gallery floor if an open balustrade is adopted. This will prevent objects from rolling over the edge of the gallery and falling on men working down below.

For loading and unloading docks and covered ways, where the wear is very heavy, a good concrete road with British Reinforced Concrete reinforcement will give satisfactory service providing it is kept in a good state of repair. A watch must be kept for cracks or wear which will occur in places where there is continuous unloading at one position. These worn places can be repaired with "Ferminard," which can be laid on the worn part and stamped in after painting the worn part with a fixing or priming dressing. The floor can be used immediately after laying, and will last for some considerable time.

For plating shops or similar floors where water is present, a well-laid granolithic floor will give good results, providing it does not get extra heavy wear.

Brick Party Walls between departments, especially where highly inflammable work, such as cellulose spraying, is carried out, should

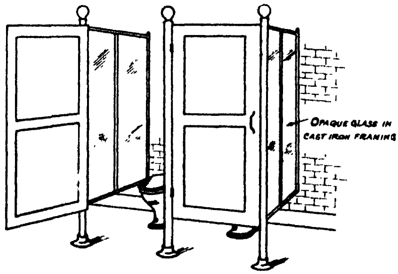


FIG. 186. METAL-FRAMED LAVATORY PARTITIONS

be carried through the roof, thus isolating the one part of the roof from the other in the event of fire. Fireproof doors should be fixed on the side that has the least fire risk.

In the interests of fire prevention, windows in brick party walls should be stationary. Wired glass should be used for the panes. Some brick partitions are strengthened by metal reinforcement such as "Expanmet"; or a special form of reinforcing surface wire may be used in conjunction with special indented bricks. About every fourth course is so reinforced.

Lavatories. With a single-story factory it is difficult to arrange for central lavatory accommodation, and the most satisfactory method is to build the lavatories overhead. Only a light construction is necessary, and providing the stanchions and the steelwork are made strong enough in the first place to carry extensions, the cost in this case should not be high. Cast iron soil pipes should be used inside the factory, with earthenware outside. The trouble usually experienced in lavatories due to the defacing and marking of paintwork with drawings and writing can be practically eliminated if the lavatories are white-tiled, the w.c. partitions being of opaque

glass in cast iron framing. Details of this construction are given in Fig. 186. The Factories Act stipulates that the following sanitary conveniences shall be provided—

Females		1 convenience for every 25.
Males	Up to 100	1 convenience for every 25.
	100 to 500	1 convenience for every 25 for first 100. 1 convenience for every 40 thereafter, provided sufficient urinal accommodation is made available.
	Over 500	1 convenience for every 60, provided sufficient urinal accommodation is available and a check or some other method is instituted to regulate their use, and a certificate is obtained from the Factory Inspector.

MULTI-STORY FACTORIES

Where the cost of land is high, or where the amount of ground available for possible future extensions is limited, the multi-story building is, of course, the only type of factory to be considered. Even when extra ground is available, this construction may prove the best type of building for some classes of manufacture, particularly when the raw materials can be conveyed to the top floor and eventually gravitate to the ground floor as a finished product.

With a large works of this type, due to the smaller ground area covered, it is easier to get from one part of the factory to another—by modern high-speed lifts—thus facilitating good supervision. Service pipes and cables are usually reduced in length, the size of storm water drains is considerably reduced, due to the smaller roof area, and roofing, gutter cleaning, and maintenance are also reduced to a minimum. Good ventilation is much more easily arranged. Lavatory blocks can also be suitably arranged, one over the other in a more or less central position with reduced lengths of soil pipes, etc.; and if an extra floor is added, say, for canteen or office use, it is easy to extend the lavatory accommodation.

Where heavy machinery is manufactured, the cost of conveying from one floor to another is considerable. The lighting is not so good as the single-story type with north light, and unless the central part of each floor can be used for necessary storage, it is not advisable to have a greater width than 60 ft. Large spans cannot be built without great cost, due to the stronger floor construction necessary; also the fire risk is greater.

The clear height between floors is usually similar to that for the single-story type, i.e. 12 ft. to 14 ft., the percentage of glass as compared with the floor area varying between 30 and 35 per cent.

The usual methods of construction in use at the present time are the *steel-frame* and the *reinforced-concrete* systems, each having its respective advantages.

The Steel-frame System, for instance, can be fabricated away from the site, being delivered and erected as needed, thus leaving

the site clear for carrying out any other operations that may be required. Also, in the event of future extensions being necessary it is a very simple matter to drill the existing members for the purpose of forming connections.

It may be mentioned here that welding is becoming popular in constructional steelwork to-day. Stanchion bases, pillar brackets, angle stiffeners, etc., which formerly would have been riveted, are now welded to the main steelwork before dispatching to site.

The principal disadvantage with steel-frame work, however, is the cost of maintenance. Also, in regard to design, most bearing members, especially those in the form of rolled steel joists, necessitate the provision of steel where it is not architecturally essential, as explained in the next paragraph.

The Reinforced Concrete System, on the other hand, is economical. Most of the materials can be found near the site, and when properly designed the structure can be made to carry heavy loads on relatively small members; this is especially the case with filling walls. For example, a brick filling wall 9 in. thick—which is usually used as a means of protection against rain—weighs about 86 lb. per ft.^{2} of surface area, whereas a reinforced concrete panel, say, 3 in. thick and weighing about 38 lb. per ft.^{2} surface area, would be sufficient. In this case, the panel will not be perforated and will be cast *in situ*, being homogeneous with a top and bottom beam. The whole may be designed as a girder, thus further reducing the sizes of the beam members and bringing about, in consequence, a saving in materials and a corresponding reduction of weight on the foundations. Where reinforced concrete is used, and it is anticipated that extensions or alterations to the building will ultimately be necessary, provision should be made by inserting sleeves or by forming pockets, etc., to provide for necessary connections.

Floor Construction. The type of floor to be adopted depends largely on the processes to be carried out in the particular department, and may range from a reinforced-concrete floor cast *in situ* with the beams, to one of the various patented systems of floor construction now on the market, such as the Seigwart, Truscon, Homan & Rogers, J. A. King, or Kleine. These patent floors generally take the form of hollow beams, some built up in sections, others cast to length. They have the advantage of lightness combined with strength, and at the same time they can furnish ducts through which the necessary services can be passed. The Kleine type (Fig. 187) is sometimes reinforced in two directions, when there is a heavy load to be carried.

Whichever type of floor is decided upon, cast iron or built-up steel pads should be provided on the underside of the floor for bolting up shafting hangers, countershafts, motors, etc., a definite standard of fixing being decided on before the building design is completed. Fig. 187 also shows different types of floor construction.

In some cases Seigwart beams are manufactured by extruding on a special machine having two wires set to cut along the top. The top remains on the "trough" during drying and burning, but is afterwards tapped with a hammer, when it readily separates from

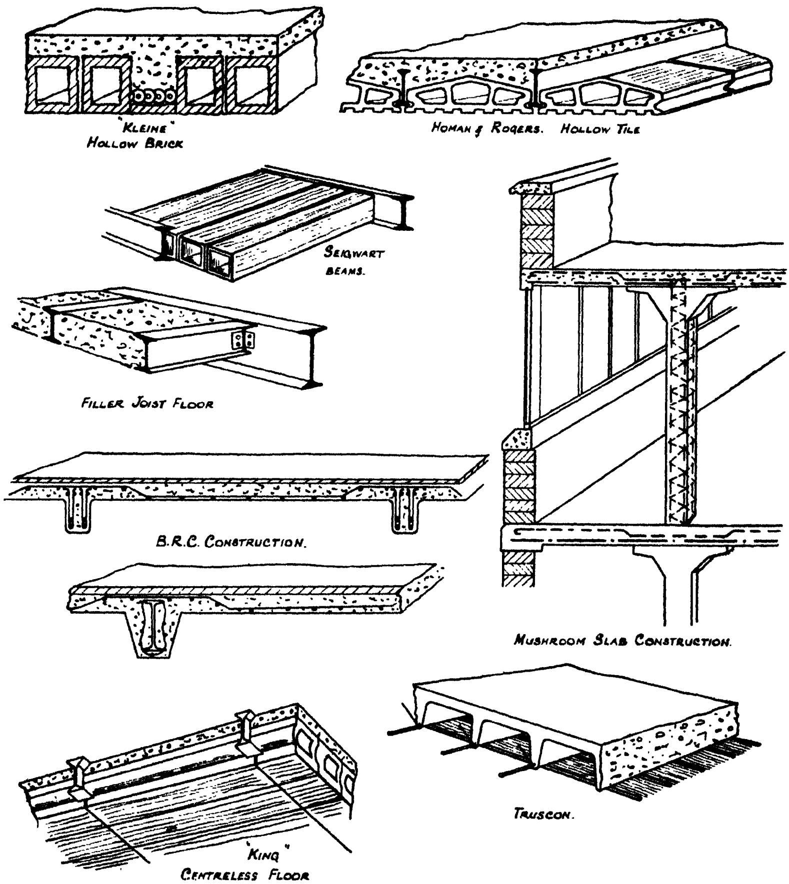


Fig. 187. Types of Floor Construction

the trough and so forms a convenient conduit and lid in which electric mains can be laid.

Whilst the author has no leaning towards any particular type, as so much depends on the class of manufacture, he has found that the Kleine system does give good service and is fairly adaptable to most circumstances. Floor surfaces similar to those which have

been dealt with earlier in this chapter under single-story buildings, may be used.

A typical Kleine floor might have blocks 10 in. by $6\frac{3}{8}$ in. by 8 in. deep. The thickness of the walls of the blocks is $\frac{3}{4}$ in. and of the central web 1 in. In some types each block has a groove $\frac{1}{2}$ in. deep in the sides, at about $\frac{3}{4}$ in. above the base. The floor is made up of blocks laid $\frac{1}{8}$ in. apart, with a $\frac{1}{2}$ in. steel bar between each one. A mortar composed of 3 parts of sand to 1 part of cement is used as a filling, and is spread as a covering over the floor to a depth of $\frac{1}{2}$ to $\frac{3}{4}$ in. When the hollow bricks have side grooves, a stronger floor can be made by running the steel bars along the grooves. A definite camber is often given to such floor blocks, in order to provide maximum thickness of covering at the joins.

Roofing. The roofing almost universally adopted is the north light type, which has been dealt with on page 296 *et seq.*

Combined Single- and Multi-story Factories

This type of factory is perhaps the ideal for most classes of manufacture, as it combines the advantages of both type, whilst it reduces some of the disadvantages. For instance, in the manufacture of electrical equipment, the coil winding and the production of small pressings and other small parts can be carried on in the multi-story building, the finished components eventually finding their way down to the ground floor, while the erection and the heavy work, such as that of the foundry, heat-treatment shops, etc., can be carried out with a minimum of handling in the single-story buildings. As another example, in the manufacture of artificial silk, the raw material can be pumped to the churn room on the top floor, whence it passes through the various stages, eventually reaching the ground floor as the manufactured material. It can then be finished and packed in the single-story part of the factory.

Provided the building layout is properly arranged, it is easier to build extensions with the combined type without interfering with production than is the case with the multi-story type. The extensions can often be of the cheap single-story pattern, although, if very much more space is required, the main multi-story building can be extended. In laying out the combined type of factory, care must be taken to ensure that provision is made for adding extra wings. Fig. 188 shows a plan of typical factory buildings of the combined pattern, with provision for extensions of both types. Whilst this may not suit every type of manufacture, it will serve as a guide to the sort of provision that should be made for extension. The design illustrated can often be arranged to give an impressive façade facing the main road.

Light Wells. The walls of the light wells should always be of a light colour. Glazed bricks or tiles for the first and second story may well repay the extra expenditure, by reducing the lighting bill.

NOISE AND VIBRATION IN BUILDINGS

The elimination of vibration and noise is a very important factor in a great many factories to-day, and the Works Engineer usually has two types of problems to deal with: (1) the isolation of the vibration and noise from moving machinery such as Diesel engines, turbo-alternators, pulverizers, etc.; and (2) the elimination of noise from special silence rooms or cabinets—such as those used for wireless tests, etc.—which are situated in manufacturing departments, or the protecting of sensitive instruments from the surrounding vibration. Sounds are vibrations, which may be subdivided here into (*a*) ground or mechanical vibrations caused by

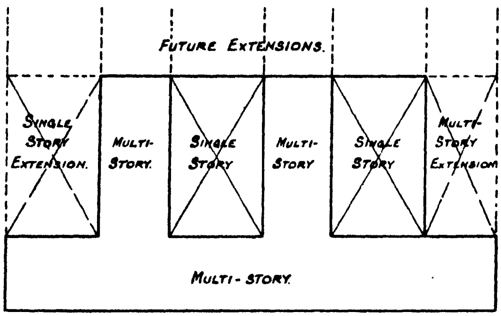


FIG. 188. LAYOUT OF SINGLE- AND MULTI-STORY BUILDING

the machines and transmitted through the foundations to the walls or steelwork; and (*b*) air vibrations, transmitted through the air.

In the first type of problem, ground vibration is the main cause, and allowance must be made for this when the foundations are designed for the particular machine. When large machines are to be installed in, say, the basement of a multi-story building (where vibration can cause a great deal of damage to floors and walls), it is advisable to consult a firm of experts, such as Messrs. Absorbit, Ltd., or Messrs. Christie & Grey. For steel-framed buildings, obviously, no holding-down bolts for machinery should be fastened down in direct contact with the steelwork.

The machine foundations are usually in the form of a large raft of concrete, supported by means of specially prepared cork, such as "Korfund" or "Coresil," or a combination of springs, cork, and felt with an air space of about 1 in. around the sides. The springs may be in the form of semi-elliptic leaf springs, or coil springs housed in a vibro-damper (Fig. 189). Vibro-dampers are of special value in eliminating the transmission of vibration from reciprocating machinery, whether prime movers, compressors, or pumps.

In the case of ventilating plant mounted upon the roof of a

building, vibration which would otherwise be transmitted by holding-down bolts throughout the roof can be avoided by mounting the fan on a heavy concrete block, between which and the roof itself a 3 in. cork slab is inserted. No bolts pass through the slab to the

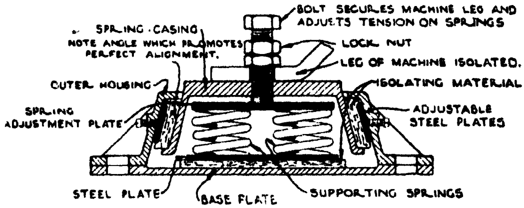


FIG. 189. SECTION OF VIBRO-DAMPER
(*Practical Acoustics for the Constructor* (Glover))

building, and consequently the concrete block must be sufficiently heavy to withstand tendencies to overturn, due to high wind pressure; moreover, the roof must be strong enough to bear the total weight.

Air vibration rarely gets beyond the room in which it occurs but when it is essential to reduce all noise to a minimum, this can be accomplished by lagging the machine which causes the trouble with a suitable air-dense material. Fig. 190 shows a coal pulverizer foundation, the absorbing medium being "Korfund." With this class of machine the vibration is considerable, but practically none of it is transmitted to the next room. For some types of plant, such as motors, etc., direct mounting on vibro-dampers may be sufficient.

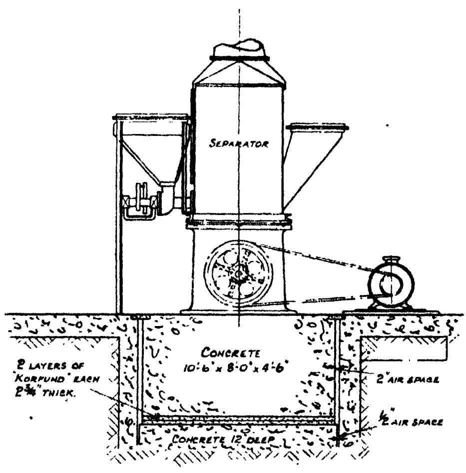


FIG. 190. PULVERIZER FOUNDATION WITH "KORFUND" AS A SHOCK-ABSORBING MEDIUM

Excessive vibration and noise from machines may be due to imperfect balancing. In such cases the only remedy is to balance the machines again as nearly as possible; if out-of-balance forces still remain, a dynamic absorber should be tuned to neutralize the vibrations arising. At the same time, all loose and worn parts should be replaced, and the bearings examined to ensure that efficient lubrication is taking place.

In the second type of problem, the building of sound-proof cabinets or silence chambers, needs special care, especially as more often than not these cabinets have to be of a portable nature,

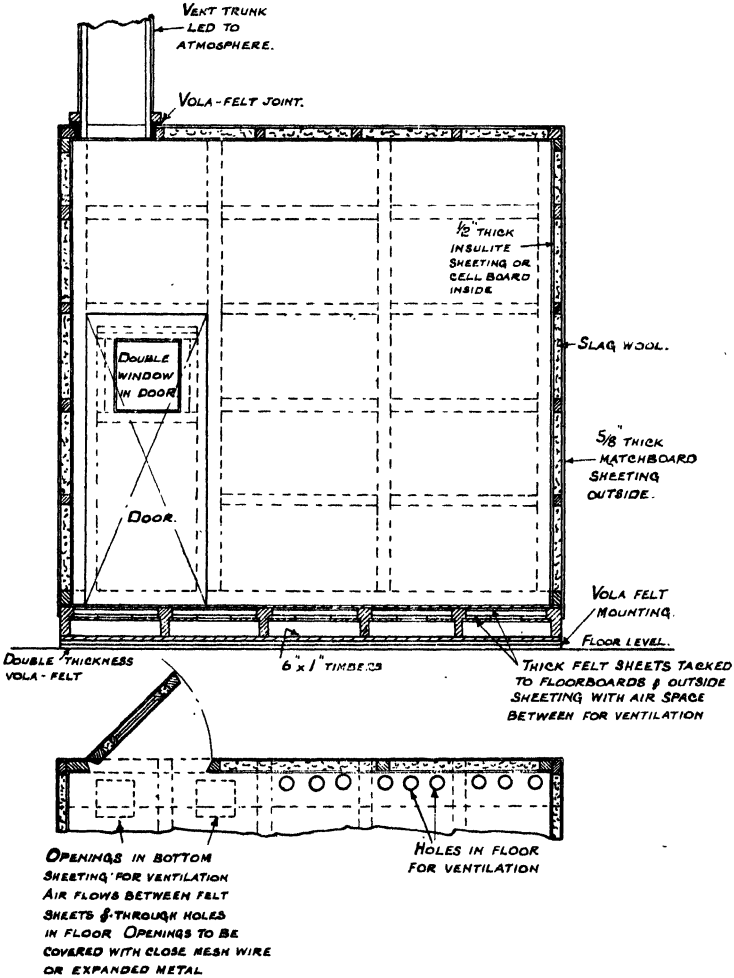


FIG. 191. SILENCE CABINET FOR COMMERCIAL USE

inasmuch as the line of production may have to be altered from time to time. Not only must the elimination of sound of both air- and ground-vibrations from outside sources be considered, but also the reverberation or reflection of sounds from the walls and ceiling

of the room itself. These sounds may continue long enough to be detected by the ear after the actual note or sound has been stopped or changed; and where such work as, say, the testing of loud-speakers is involved, it is not possible to get a true impression of the clarity of the instrument.

Dealing with the floor first, ground vibrations from outside sources have to be eliminated. The use of an elastic material is necessary, such as "Antiphon" or "Volafelt," thus creating a "floating" floor. When possible, it is a help to have the whole cabinet "floating." The outer walls, if of brick, should have a timber lining to which is attached the selected interlining insulator, which may be rock wool, "Absorbit," class A, or in some cases seaweed quilting. If the cabinet is built up of wood framing the outer covering may be of "Insulite," "Cell Board," or even match boarding, the framing being filled on the inside in a similar manner to the brick-built type. In either case this filling can be kept in position by fine-mesh wire netting or fly netting; where a cabinet is used a great deal, "Insulite," "Cell Board," or "Absorbit," class C, may be good enough for commercial purposes. The soundproof room constructed by the Metropolitan-Vickers Electrical Co., Ltd., for the testing of machinery with a view to noise reduction, has the walls, floor, and ceiling covered with an interior lining of cotton waste 8 in. thick. This lining is held in position by wire netting. Slag wool has an advantage over cotton waste in that it does not harbour vermin.

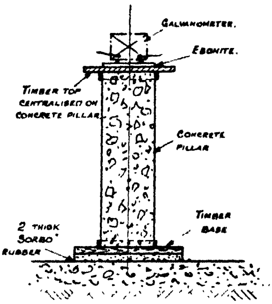


FIG. 192. ANTI-VIBRATION MOUNTING FOR MIRROR GALVANOMETER

Fig. 191 shows a type of cabinet which is quite suitable for commercial use.

Isolation of Instruments. Where instruments such as mirror galvanometers have to be housed, it is essential to keep them free from vibration, otherwise the light beam will not give a steady reading on the scale. The usual method is to cast a concrete pillar or stand and to carry the foundations through the floor, with an air gap between the floor and the sides of the stand. This arrangement can be dispensed with if the concrete stand is fitted to a wooden base and mounted on "Sorbo" rubber 2 in. thick, as shown in Fig. 192.

FACTORY PAINTING

The Factories Act stipulates that factory interiors shall be lime-washed every fourteen months. Exemption from this requirement can be claimed in certain trades and circumstances. Where a washable water paint of a given specification is used, and providing

the interior is painted with two coats, repainting with at least one coat is only required once in every three years, as long as paint surfaces are washed at least once in every fourteen months. Where oil paint is used, repainting must be done every seven years providing the surface is washed down every fourteen months.

Apart from the instructions issued under the Factories Act, it is to a firm's own advantage to keep the inside of its factories clean. Not only is there a saving in electric lighting, and an increased cleanliness in the finished products, but also there is the psychological effect on the employees, who will work much better and more accurately. These considerations make the painting of factories a very important item. The same applies to the cleaning of windows and roof glazing. As pointed out in Chapter IV, the author carried out a test on a piece of roof glass in a clean suburb; one sheet was left uncleaned for twelve months, and then taken out and tested for light absorption with a foot-candle meter and an electric lamp. The average readings over the whole sheet of glass gave 58·4 per cent light absorption. A good cleaner for outside glass, providing care is taken in its use, is "Morlite."

With glass partitions and windows the ordinary method of "leathering" a window takes considerable time and costs money. The author has used a Carter "window washer" with great success. It comprises a small water container with a felt pad for washing, and a rubber squeegee for polishing. One man working with the washer is equivalent to three men using the old method. The washer is made by the Carter Products Corporation, Cleveland, Ohio.

For paintwork in coastal districts, special types of paint are advisable on account of the difference in the atmospheric conditions. Experiments made in the U.S.A. indicate that the best results in such cases are secured by mixing the pigments, e.g. the United States Lighthouse Department uses white paint made from pigment consisting of 25 per cent white lead and 75 per cent zinc oxide.

Internal Painting. The standard colour for steelwork roof trusses, etc., is usually light green; where the work carried on in the shop is clean, cream is sometimes used. Successful experiments have been tried with aluminium paint, which greatly increases the reflected light. The covering and lasting properties of a first-class aluminium paint are very good. As mentioned in an earlier chapter, it is a good plan to paint all hangers, overhead motors, guards, and even large pulleys aluminum; they can easily be touched up and there is no difficulty in matching the colour, as there is with other paints. For ceilings, a light cream is preferable to white, as the latter is inclined to look dingy after a few months.

A good colour for the walls is a light biscuit, with a chocolate or dark brown dado up to 4 ft. from the floor. A good water paint or distemper should be used for both ceilings and walls. There are

now so many good water paints or distempers on the market that it is hard to discriminate between them. In many cases the slight extra expenditure entailed in the use of a good oil-bound distemper is well justified, as most of the first-class brands will really withstand washing. For water paints the author has a preference for types such as "Walpamur"; and for oil-bound distempers, products similar to those marketed under the name "Keystone." Both the brands mentioned have good covering power and are easy to apply.

Exterior Painting. Under normal conditions, outside painting should be done every fourth year. Where acid or other injurious fumes are present it will be necessary to repaint more often. As regards finish, there appears to be a preference in recent years to provide a hard gloss paint for the finishing coat. It is important, however, that both under-coats and finishing coats for external use should be obtained from a reliable firm of manufacturers.

Cheap paints never prove economical in the long run.

Acid-resisting Paints. Where acid fumes have to be contended with, a good acid-resisting paint finished with a coat of acid-resisting varnish, such as that supplied by Messrs. Griffiths Bros., of Bermondsey, should be used.

Where the paintwork is in direct contact with sulphur fumes or sulphuretted hydrogen, a lead-free paint must be used, as the sulphur attacks the lead, forming lead sulphide, which turns the paintwork black. In one case where a room subjected to these fumes had been painted white with a lead-free paint, discoloration took place at the point where the painting had been commenced, and its cause was eventually traced to the use of a paint brush which had not been properly cleaned and had previously been used for a lead paint.

For cast iron or steel gutters, etc., in the vicinity of fumes, the author has tried several types of bituminous paints and red-oxide paint, and in his experience the latter has lasted much better. A paint having a zinc base has proved satisfactory where light colours are required.

Bituminous paints are liable to deterioration in sunlight, as the sun's actinic rays cause decomposition to take place. By mixing the bitumen with finely divided carbon, this can be largely avoided, as the carbon prevents the absorption of most of the actinic rays. Other pigments may be mixed with the bitumen to give varying degrees of preservation, in proportion to the amount of pigments used.

MISCELLANEOUS

Overcrowding of Workshops. The Factories Act states that the proportion of cubic feet of space in a factory or workshop to the persons working therein should not be less than 250 per person during normal working hours and 400 during overtime. It is

essential, of course, that a notice shall be affixed in every factory or workshop specifying the number of persons who may be employed in each room of the factory or workshop. Emergency doors must be put in suitable positions to suit the local authorities' requirements, and made to open outwards.

Works Offices should be made up of sectional partitions either of steel or wood. It is then easy to change the size of an office or to remove it to a new position without waste of materials or the necessity of redecoration.

Small Erections and Sheds. The line of extension should be carefully planned. Sheds or shops of a temporary nature should not be built in such positions that they may have to be taken down in a few years' time when extensions are made.

Acid-dipping Shops. In such shops the walls should be coated to a height of 4 to 6 ft. with "Prodorite" or some similar bituminous rendering. All framing and window sashes should be of wood, and windows should always be arranged on an outside wall to allow of the exhausting of the acid fumes to the atmosphere. Fans are necessary to withdraw these fumes, and whilst the standard form of fume exhaust fan, with extended shaft and outside motor, operates very well, the constant renewal of fan runners or blades is costly. Fig. 184, on page 307, shows a method that has been used satisfactorily. Air is drawn in through the side walls, causing a slight pressure in the shop; thus the air to be exhausted passes through the vent over the acid baths, thereby keeping the fumes away from the operators' faces. The air is drawn from the plating shop and thus helps to ventilate this department also. Doors must, of course, be self-closing.

Where the washing or cleaning waters enter the soil drain, the local authorities' chemists may enforce the neutralizing of the acid entering the public soil drains. The acid can be neutralized by the use of hydrated lime or soda ash, the latter being the better agent, since, for satisfactory neutralizing with the former, excess lime would have to be used. It is essential, when lime is used, that the neutralizing agent shall be kept in a good state of suspension by continuous agitation. If this is not done, there is a possibility of the pipes becoming stopped up; thus, although lime is cheaper, the maintenance is much greater than when using soda ash. The proportion of neutralizing agent to waste acid will depend on the strength of the latter. Taking this strength as 100 per cent, the amount required would be—

Soda ash: approximately equal parts of soda ash and acid.
Lime: approximately three parts of lime to four parts of acid.

The solubility of soda ash in water is 7 per cent. From this the capacity of the required tank can be estimated.

Battery Rooms. Whilst it is not so essential to have battery or

accumulator rooms on an outside wall, it is preferable, if it can be arranged, so that natural—instead of forced—ventilation can be used. Good ventilation is essential to exhaust the oxygen and hydrogen given off from the batteries, thus preventing the formation of an explosive mixture. It is also necessary for reducing the temperature of the batteries during heavy charge or discharge periods, and to carry off the spray, thus preventing the rotting of wooden battery stands. It is advisable to use a somewhat similar floor construction to the dipping shop, except that pre-cast bituminous paviors may be used in place of blue bricks. A good acid-resisting asphalt floor, such as those laid by Limmer Asphalt Co., or Messrs. Val De Travers, will also give satisfactory results. This type of floor should be washed down, say, once a week, to get rid of the accumulated acid and dirt.

Steelwork in battery rooms may be protected by painting with acid-resisting paint. Lighting switches should be as far from the spray or gases as possible; actually they are better fixed outside the entrance. When forced ventilation is necessary, the air inlets should be arranged as near the floor as possible and the outlet at the highest point in the roof or ceiling, so as to ensure that there are no stagnant pockets. The fan should be arranged in the outlet, otherwise there will be a slight pressure in the room which may help to cause an explosion.

Elimination of Obnoxious Gases. Where obnoxious fumes are given off in rubber or ebonite manufacture, such as sulphuretted hydrogen, etc., complaints may be received from the local authorities. The best method of reducing the nuisance is by passing the fumes through a coke fire or under a boiler grate. This is not always practicable, however, and the only means then of getting rid of the greater part of the fumes is by building a very high chimney and dispersing the fumes over a very large area, or by scrubbing the fumes. Whilst it is impossible to remove the smell completely, a scrubbing tower such as that shown in Fig. 193 will greatly reduce the nuisance. A 1 per cent solution of caustic soda should be used.

Floor Wear. The wear on floors can be considerably reduced if rubber-tyred transport trucks are used; either solid rubber cushions may be fitted, or the new small Dunlop pneumatic tyres. The use of these tyres will also considerably decrease the amount of noise.

Machine Foundations are usually required in a hurry and if a rapid-hardening cement, such as "Ciment Fondu" is used, the machine can start working within twenty-four hours. A concrete mix using ballast, sand, and "Ciment Fondu" in the ratio 4 : 2 : 1 will attain a strength from 7 000 to 8 000 lb. per in.^{2} within twenty-four hours. Another point in favour of "Ciment Fondu" is that a normal mix is not affected by frost; owing to the quick chemical action, it becomes quite warm, and is therefore immune from freezing. Concrete made with this cement should be kept damp,

either with wet sacks or by sprinkling with water from a watering can, during the setting process.

Paving Slabs. Where boilers are fired with pulverized coal, the fine ash, which is composed of about 80 per cent silica, makes an

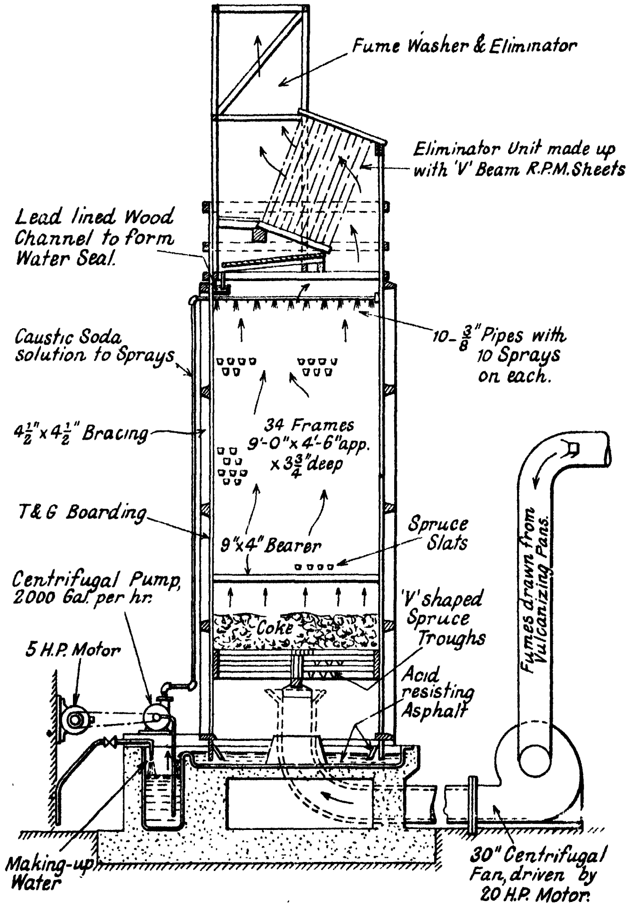


FIG. 193. FUME WASHER AND ELIMINATOR

ideal binder for paving slabs, in conjunction with broken bricks, and the author has had some 2 000 ft. run of footpaths paved by this method. The mixings are as follows—

1 part broken brick.
2 parts flue dust.
1 part cement.

The slabs are faced to about $\frac{3}{8}$ in thickness with a mixture of $1\frac{1}{4}$ parts of dust to $1\frac{1}{2}$ parts of granite chippings and cement; the total thickness of the slabs should be at least 2 in. and they should be set in mortar, $1\frac{1}{2}$ tons being sufficient to form a path 170 ft. long and 6 ft. 3 in. wide. The overall cost, including removal of the former ash path and laying with slabs, is about 1s. 5d. per yd.[2]

Mixers. A small brick crusher and portable petrol-driven mixer is very useful, not only for this work but for putting in machine

TABLE XIX

LOAD IN TONS FOR DIFFERENT SPANS

I BEAMS I		SAFE LOADS IN TONS UNIFORMLY DISTRIBUTED.																			
Size in Inches	Weight per Foot Lbs.	Spans in feet.																			Section Modulus
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	36	40	44	
		"A" Girder Sections.																			
24×7½	90							75·4	67·9	60·3	54·3	49·4	45·2	41·8	38·8	36·2	33·9	30·2	27·1	24·7	203·6
22×7	75					70·1	67·7	58·1	50·8	45·2	40·6	37·0	33·9	31·3	29·0	27·1	25·4	22·6	20·5	18·5	152·4
20×6½	65					57·3	54·5	46·7	40·9	36·3	32·7	29·7	27·2	25·2	23·4	21·8	20·4	18·2	16·3	14·9	122·6
18×6	55				50·2	49·9	41·6	35·6	31·2	27·7	24·9	22·7	20·8	19·2	17·8	16·6	15·6	13·9	12·5	11·3	93·53
16×6	50				46·3	41·2	34·3	29·4	25·8	22·9	20·6	18·7	17·2	15·8	14·7	13·7	12·9	11·4			77·26
15×6	45				41·9	35·0	29·2	25·0	21·9	19·4	17·5	15·9	14·6	13·5	12·5	11·7	10·9				65 59
14×5½	40			39·8	35·9	28·7	23·9	20·5	18·0	16·0	14·4	13·1	12·0	11·0	10·3	9·58					53·87
13×5	35			35·5	29·1	23·3	19·4	16·6	14·5	12·9	11·6	10·6	9·69	8·95	8·31						43·62
12×5	30		31·4	30·7	23·0	18·4	15·3	13·1	11·5	10·2	9·20	8·36	7·66	7·07	6·57						34 49
10×4½	25		26·0	21·7	16·3	13·0	10·9	9·32	8·16	7·25	6·52	5·93	5 44	5·02							24·47
9×4	21	24·3	24·0	16·0	12·0	9·61	8·01	6·87	6·01	5·34	4·81	4·37	4 01								18·03
8×4	18	20·2	18·5	12·4	9·27	7·42	6·18	5·30	4·64	4·12	3·71	3·37									13 91
7×3½	15	15·8	13·7	9·12	6·80	5·47	4·56	3·91	3·42	3·04	2·74										10·26
6×3	12	12·4	9·33	6·22	4 66	3·73	3·11	2 67	2·33	2·07											6 996
5×2½	9	9·90	5 82	3·88	2·91	2·33	1 94	1·66	1·45												4·364
4½×2	7	7·70	3 94	2·63	1·97	1·58	1 31	1·13													2·957
4×1¾	5	4·89	2·44	1·63	1·22	·98	·81														1·832
3×1½	4	2·95	1·48	·98	·74	·59															1·107
		"B" Heavy Beams.																			
18×8	80					73·8	63·8	54·7	47·9	42·5	38·3	34·8	31·9	29·4	27·3	25·5	23·9	21·3	19·1	17·4	143·6
16×8	75				67·9	64·9	54·1	46·4	40·6	36 1	32·5	29·5	27·1	25·0	23·2	21·6	20·3	18·0			121·7
14×8	70				58·0	53·8	44·8	38·4	33·6	29·9	26·9	24·4	22·4	20·7	19·2	17·9					100·8
12×8	65				46·4	43·4	36·1	31·0	27·1	24·1	21 7	19·7	18·1	16·7	15·5						81·30
10×8	55				36·0	30·8	25 7	22·0	19·2	17·1	15·4	14·0	12·8	11·8							57 74
10×6	40			32·4	27·3	21·8	18 2	15·6	13 7	12·1	10·9	9·93	9·10	8·40							40·96
9×7	50			32·4	30 8	24·7	20·6	17·6	15·4	13·7	12 3	11·2	10·3								46·25
8×6	35			25·2	19·2	15·3	12·8	11·0	9·59	8·52	7·67	6·97									28·76
6×5	25		17·8	13·4	10·0	8·03	6·69	5·73	5·02	4·46											15·05
5×4½	20		13·1	8·90	6·67	5·34	4·45	3·81	3·34												10·01
4×3	10	8·64	5·19	3·46	2·60	2·08	1·73	1·48													3·893

By permission of Messrs. Dorman, Long.

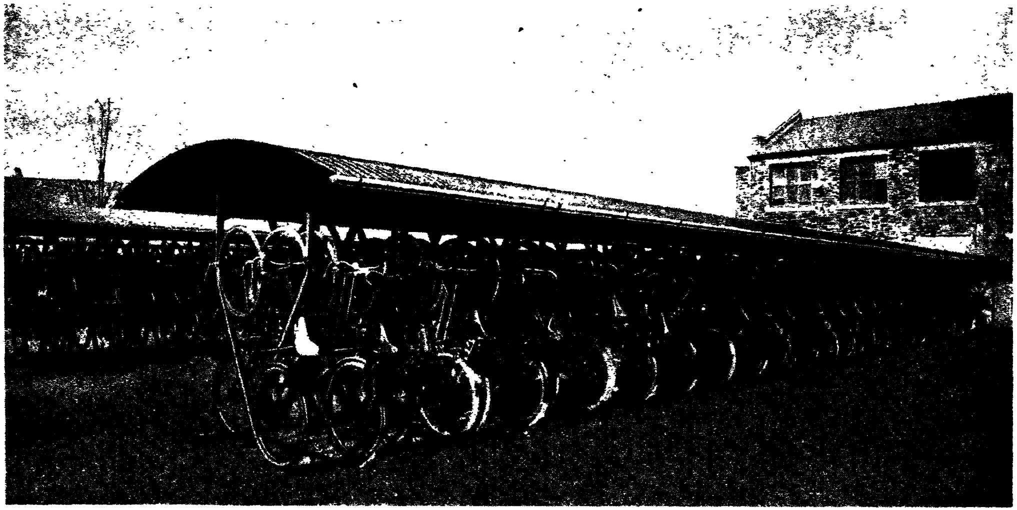


FIG. 194. CYCLE RACK
(Constructors, Ltd.)

foundations. Apart from the assurance of proper mixing, the time saved by running the mixer right on the site means that the work is done better, quicker, and more economically. The author has used a "Ransome Featherweight" mixer with a batch capacity of $4\frac{1}{2}$–$3\frac{1}{2}$ ft.^{3} driven by a Lister 4 h.p. petrol engine; the mixer is capable of a daily output of 30 yd.^{3}

Services. In quite a number of factories, the lack of adequate facilities for service pipes and cables is noticeable. When laying out new buildings, this point must be remembered, and cable and pipe ducts or subways provided. For single-story buildings an outside gantry is perhaps advisable, as with this scheme valuable floor space is released, and a clear way is left for overhead conveyers, etc., since it is then only necessary to have relatively small cables and pipes inside the factory.

Travelling Cranes. Where cranes are used in shops or loading bays, one standard track should always be employed. Due to a change in the line of production or layout it may be necessary to exchange a hand crane for an electric one; or, if a heavier crane is necessary, the crane to be replaced can be used instead of one of the hand cranes.

Steelwork. Space will not permit of a detailed treatment of steel construction owing to the number of tables required for the numerous different sizes of steel sections, also to the length of the L.C.C. Regulations, etc. This subject is well covered in the books published by the different steel manufacturers; these are usually supplied free of charge to Works Engineers. Perhaps the most-thumbed page in such a book is the table giving the safe load in tons for different spans with a uniformly distributed load. A copy of Messrs. Dorman Long's tables is reproduced in Table XIX, by their kind permission.

Cycle Accommodation. With the building of factories on the outskirts of cities and towns, the cycle has become popular with workpeople to-day, and adequate cycle accommodation has become a big problem. It is now possible to buy suitable compact steel cycle racks, ready for erection, which take up a minimum of floor space. Fig. 194 shows a typical example. Cycle racks of the old type usually require a lot of maintenance, but the new steel type can be installed and forgotten, except for the usual periodic painting.

CHAPTER XI

MISCELLANEOUS EQUIPMENT

CONVEYERS AND TRANSPORT

CONVEYERS to-day are—or should be—an integral part of the plant of almost every factory. Although they are used primarily to convey goods or partly finished articles from one process or operation to another, it is not always fully realized that they are extremely useful as a means of storage. Whilst any of several methods may be adopted to convey goods mechanically, there may be only one ideal method combining economy with low initial costs.

Gravity Roller Conveyer. This is, of course, the most economical device when it is possible to arrange a slight fall to enable the articles to move along by gravity, or when operators can perform one operation, say to a motor car engine, and push it along to the next operation.

With the roller conveyer, goods can be passed from one shop to another with no other costs than the initial outlay. These conveyers can be erected anywhere, with suitable switches and curves to suit any particular job, and can be moved round to suit any re-arrangement of plant. Other types of conveyers or elevators can be used in conjunction with them. Sometimes, instead of rollers, small ball-bearing wheels are used and fitted on the outside of the angle iron frame, so forming a light portable type.

When goods have to be transported from upper to lower floors, friction spiral chutes or roller spirals can be used. For elevating goods, "subveyers," vertical elevators, slat-, chain-, or belt-inclined elevators may be used, depending on the class of work.

Belt Conveyers. These are, of course, power-driven, and when laying out a system, care must be taken to supply the conveyer manufacturer with complete information as to the weight and number of articles to be carried in a given time, so that a correct speed can be arrived at. The belts may be in the form of stitched cotton, slatting, chain, or woven wire, according to the class of work carried. When cotton belts are used they are usually arranged flat and the bottom strand can be used for conveying goods in the opposite direction, such as empty containers or boxes. The belting runs on idle rollers fitted with ball bearings, the spacing being usually between 6 in. to 12 in., according to the load.

Slat conveyers are formed of wood slats mounted on two lengths of conveyer chain, forming a moving platform; they are generally used for dealing with boxes, barrels, sacks, and for heavier work than could be carried on a cotton belt.

Chain Conveyers are usually adapted to suit a particular job, such as the conveyance of beer or milk bottles, oil barrels, etc.

Woven Wire Belts are used on drying or cooling conveyers and are formed of galvanized wire of various gauges to suit the particular work involved.

Overhead Chain Conveyer. Owing to its adaptability, this is perhaps one of the most useful types of conveyer in operation to-day. Work can be carried from one floor to another and dropped down to a machine or to any particular operation; articles can be carried through cleaning, enamelling, or drying operations, etc.; but, what is even more important, the conveyer can be used as storage without taking up valuable floor space. Where there is a time lag between operations, say for drying, the conveyer can be carried along the shop and back. It is composed of an overhead rail with an endless chain and trolleys, which can be raised or lowered at will; it will also negotiate sharp bends in any direction. Hooks or special types of carriers can be fixed to suit any work requiring them.

It has only been possible to explain briefly the main types of conveyers, and whilst there are many more peculiar to different classes of manufacture, it is advisable, before installing any type, to consult such a firm as Messrs. W. C. Pantins, Messrs. Fraser & Chalmers, or Messrs. E. Morris, who specialize in conveying machinery and who will put forward schemes.

Redler Conveyers. For flour, grain, cereals, etc., a vacuum system or the Redler "En Masse" system of conveying is employed. The author has used conveyers of the latter type for some considerable time for pulverized coal and "smudge," and they render very good service. They are composed of specially shaped links passing through a box or trough, and are capable of carrying a load of a depth approximately the equivalent of the width of the chain, the load travelling at the same speed as the chain and in a quiescent mass—the returning part of the chain being carried in the top of the box. For cereals, etc., a wood troughing or box is used, but for fine coal or other abrasive materials the troughing is made of steel sheet. The usual speed is about 60 ft. per min. Elevators are also made on the same principle; Messrs. Fraser & Chalmers specialize in coal-conveying installations, some of which the author has seen efficiently conveying material over lengths of some hundreds of feet. One of the great features of this plant is that no special housing is necessary; the troughing is totally enclosed and dustproof, and the power consumption is also very low.

Where small components are made, it is surprising to find that none of the conveyer-manufacturers have produced a really light conveyer which can not only be used to transport goods from one operation to another but also for storage purposes. The lightest type the author has found is that made by Messrs. Dixons of Letchworth. The author has used some hundreds of feet of brass

curtain rail for this purpose, and has also made small overhead conveyers with $\frac{3}{4}$ in. steel tape and small pulleys running on a light angle iron; where very light articles have to be transported or stored this type of endless band has proved very efficient.

Coal Handling. This class of work covers a very large field. Whilst drag-link conveyers, belt conveyers, or grabs may be used for the transportation of coal (the type being dependent on the layout of the installation), where waggon tipplers are not installed, the usefulness of a portable conveyer for stacking is not always realized. They are very adaptable and will more than save their cost.

"Gipe" Carriers. Where process or other cards have to be sent to different departments, the "Gipe" carrier, as used in retail shops for sending the bill and money to the cash desk, will save a lot of running about. The author has one 250 ft. long giving good service.

Transport. Whilst it is undesirable to have hand trucks, it is, nevertheless, sometimes necessary. Work may be transported from one operation to another on platforms with lifting trucks; but ordinary hand trucks are sometimes used. Wherever possible, rubber tyres should be employed; small Dunlop pneumatic or solid rubber tyres will greatly decrease the noise and the wear and tear of floors.

For transport between factories, electric or petrol-driven trucks may be used. The author prefers the former type as there is no smell or noise, and the battery, provided it is charged properly and well maintained, will last about five years. With a number of "Greenbat" trucks fitted with "Chloride" electrical batteries, the running costs over a number of years has been found to be £4 6s. 10d. per week, allowing 47 hours of continuous service.

Where two or more factories are some distance apart, a light motor van with trailers or mechanical horse, made to suit the particular requirements will be found a valuable investment.*

DEGREASING AND CLEANING OF METALS

Where machined parts have to be thoroughly cleaned for plating or lacquering, or where it is only necessary to remove swarf and chips, special plant must be installed. The removal of the surplus oil is usually effected in centrifugal separators, from which the cutting oil can be reclaimed and cleaned by passing it to a tank at ground level, whence it can be pumped through a centrifugal oil separator, such as the De Laval, and then pumped into an overhead tank equipped with heating coils for sterilizing. The oil separator can be bought already fitted with the necessary pumps. With this apparatus, an appreciable saving can be made in the consumption of cutting oil.

* For analysis of running costs, see *Proc.I.Mech.E.*, 1936, vol. 133, p. 501.

This process only removes the oil, and it is then necessary to wash or clean larger components; but for small screws, nuts, etc., made on "automatics," the chips must be removed. A very efficient machine for this operation is the McKenzie chip separator. This machine has a vibrating table over which the work spreads and falls towards the outlet, an air blast which passes over the work carrying off the chips; the only necessary adjustment for large or small parts is the regulation of the air blast. This machine takes 3 h.p. and will separate a bushel of small parts per minute. Even in the case of very small work the separation is efficiently done.

The cleaning and degreasing can be carried out by *washing machines* with whirling sprays, or by using a grease solvent such as *trichlorethylene*.

Washing Machines. These are designed with a pump fixed under the base of the tank, the hot liquid, which can be heated either by steam or gas, being circulated through revolving sprays. The solution generally used consists of 8 lb. of dry sodium phosphate to 42 gal. of water. The temperatures of the solution should be 180° F. for steel, 160° F. for brass, and 125° F. for aluminium; in the latter case the temperature should not be exceeded, as the liquid will then turn aluminium black.

Trichlorethylene Degreasing Plants. Trichlorethylene is now established as the leading degreasing agent, on account of its powerful solvent properties, its non-inflammability, and its freedom from injurious action on all metals, even in the presence of water. It can be used in both the vapour and the liquid states.

In a vapour degreasing plant, a drawing of which is shown in Fig. 195, a supply of the solvent in the sump of the plant is boiled by steam, gas, or electric heating. The vapour produced at 87° C. fills the tank and is prevented from overflowing by a condensing coil arranged round the sides near the top When the vapour reaches this coil it is condensed to a liquid and drips back to the sump, thus maintaining a constant level of vapour in the plant. Beneath the cooling coil there is usually a trough in which the condensate collects before overflowing into the sump. This trough is provided with a tap which enables the distilled trichlorethylene to be drawn off quite clean and free from grease, or to be used in other ways as explained below.

When a load of greasy articles at ordinary temperature is put into the tank it condenses the trichlorethylene vapour to liquor over all its surfaces. This liquor dissolves all oils and greases present and falls down into the sump. Here the heat applied readily vaporizes the trichlorethylene liquor again, but the temperature is not sufficient to vaporize the oil which gradually collects there. After a brief immersion in the vapour bath, the articles are heated to the same temperature, namely, 87° C.; condensation ceases, and degreasing is complete. The articles are then lifted out, the adhering

film of trichlorethylene evaporates, and leaves the surfaces entirely dry and grease-free.

When the grease on the articles contains solids, such as dust or polishing-powder, it is necessary to subject the articles to trichlorethylene liquor, usually boiling, in order to wash these solids from the surfaces to which they were held by the grease bond.

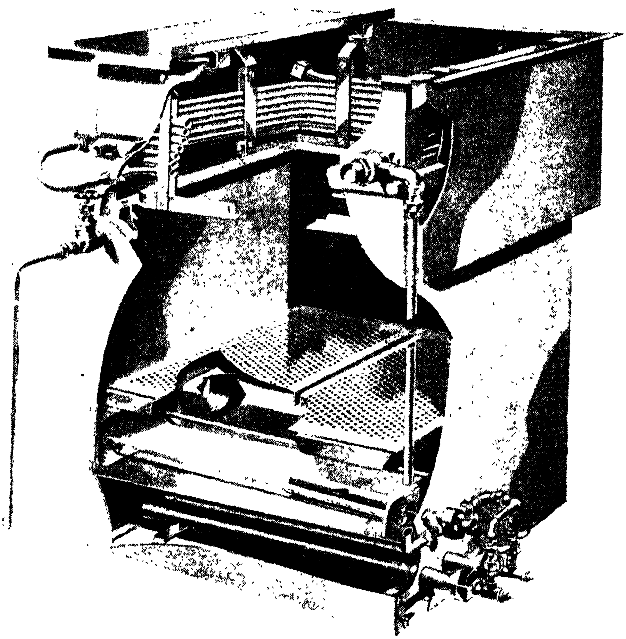


FIG. 195. DEGREASING PLANT. VAPOUR TYPE
(*Imperial Chemical Industries*)

It is not advisable to wash metal work in cold trichlorethylene only, as this may result in a high consumption of solvent, but if a wash in liquor, cold or (preferably) hot, is followed by vapour treatment, excellent results are then obtainable.

Ultimately the liquor becomes so charged with grease and solid matter that articles washed in it would not be entirely clean. Accordingly, the design of liquor-vapour plants, shown in Fig. 196, is such that condensate from the distiller trough is constantly fed to the bottom of the liquor compartment. This causes the upper portion of the liquor, which contains most of the grease and solids, to overflow into the vapour compartment. Here the oil remains, as its boiling point is far above that of trichlorethylene. In such plants the liquor compartment may require only occasional distillation,

while the vapour compartment will require more frequent cleaning in order to remove solids as well as oil.

Where the shapes of greasy articles are such that the flat surfaces cause them to stick closely together, it is preferable to degrease them completely in liquor, and dry in hot air chamber.

A suitable plant may contain three compartments of boiling

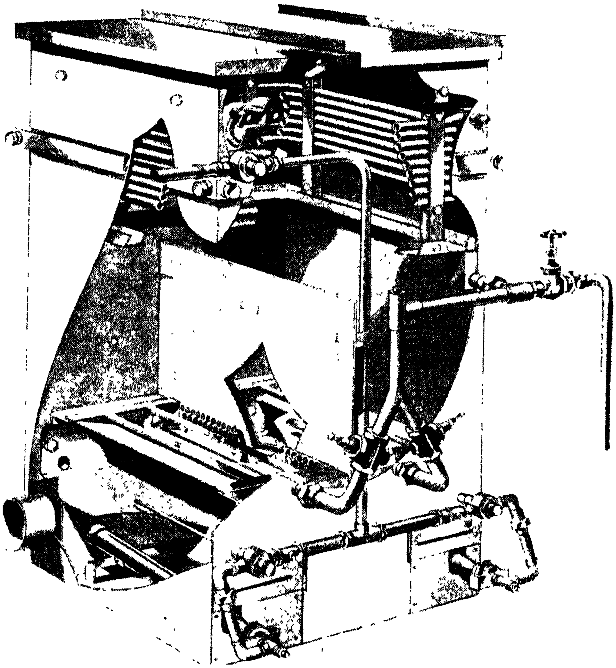


FIG. 196. DEGREASING PLANT. LIQUOR-VAPOUR TYPE
(Imperial Chemical Industries)

liquor so arranged that the distillate is fed into the bottom of No. 3 compartment; the overflow from this is fed into the bottom of No. 2 compartment; and similarly that from No. 2 to No. 1. The greasy articles are washed first in No. 1 compartment, then in No. 2, and finally in No. 3.

The bulk of the grease is removed in the first wash; the second usually completes the cleaning; whilst the third wash provides additional safety, should grease collect in No. 2 compartment faster than it is displaced into No. 1 by the flow of distillate, which is always in the opposite direction to that of the work.

The degreasing plants in general use to-day are of the vapour

and the vapour-liquor types; in size they range from those used by jewellers to those used in aeroplane factories. The chief manufacturing processes which necessitate degreasing are—

Drop Forging	After oil-quenching and oil-tempering before machining.
Drop Stamping, Pressing, Drawing, and Cold Rolling	Before annealing.
Machining	After finishing, to remove cutting oil and swarf before gauging, storing, assembly, and dispatch.
Pickling and Rustproofing	Before Sherardizing, Bonderizing, Parkerizing, Coslettizing, Carlettozing, tinning, etc.
Enamelling	Before vitreous stoving, and before applying cellulose enamels and lacquers.
Electroplating	To expose the surfaces of all base metals to the action of the deoxidizing, cleaning, and etching solutions prior to the electro-deposition of all metals.
Repair Shops	To remove oil, powder, dirt, etc., from parts of motor cars, machine tools, coal cutters, textile machinery, condensers, oil coolers, etc.

On a basis of weight, $9\frac{1}{4}$ lb. of the solvent can be vaporized by the same amount of heat as would be required to heat 1 lb. of water through the same temperature range. Imperial Chemical Industries have designed plants working on the vapour and on the combined liquid and vapour systems. Whilst these plants will render articles chemically clean, so that they can be plated or lacquered, it is sometimes necessary to leave some protective coating to prevent rust on such articles as nuts and bolts which require no extra finish. Experiments have been carried out, and by the introduction of "lanoline" into the solvent this drawback has been overcome, no rusting then taking place.

LUBRICATION

One of the most important factors in the successful running of a works is good lubrication of all moving machinery. It is even more important that the type of lubricant used is that which is most suitable for the particular job. Though a good grade of oil may be used, if its viscosity or flash point is not suited to the work in question, no matter how much the bearings or other moving parts are flooded, heavy wear and tear may take place due to bad lubrication. It will also be found that cheap lubricating oil never pays.

Oil is used to form an intervening film between the moving surfaces, thus avoiding metal-to-metal contact, which would cause friction, heating, and wear, and it must therefore have sufficient "body" or viscosity, to withstand being squeezed out. Temperature and pressure will also help to decide which class of oil to use, and, as it requires an expert's advice, it is well to consult a firm of reputation. The British Standards Institution (formerly the British Engineering Standards Association) recommend the following viscosities for the different applications (the units being seconds, in the Redwood scale)—

Light high-speed spindles	Up to 55 Redwood at 140° F.
Spindles, shafting, ring-lubricated bearings	55 to 75 Redwood at 140° F.
Electric motors, dynamos, air compressors, turbines, and gas engines	75 to 125 Redwood at 140° F.
General types of heavy engines	125 to 175 Redwood at 150° F.
For the heaviest work	175, and above, Redwood at 150° F.
Steam cylinders—	
Low-pressure saturated steam	Up to 160 Redwood at 200° F.
Medium-pressure saturated steam	160 to 190 Redwood at 200° F.
High-pressure saturated steam	190 to 210 Redwood at 200° F.
High-pressure superheated steam	Above 200 Redwood at 200° F.

Viscosity is measured by means of a *viscometer* (Fig. 197). The outer jacket A is filled with water, whilst the inner jacket B is filled with oil to be tested. A flame is then applied to the small arm or heating tube shown on the right until the required test temperature is indicated on the central thermometer. The oil is then allowed to flow into a 50 cm.³ flask, the actual time needed for 50 cm.³ to flow out being checked with a stop watch, graduated in seconds. The number of seconds is then designated "Redwood No. 1" at whatever test temperature was used (usually 150° F. for lubricating oils) and is itself the measure of the viscosity. The viscosity may also be expressed in Saybolt or Engler readings, but the Redwood scale is the measurement used in this country.

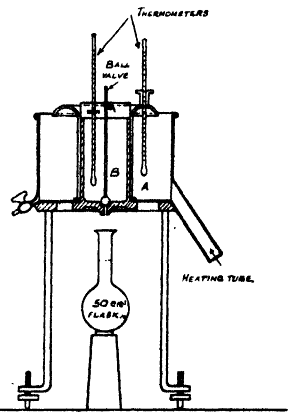


FIG. 197. VISCOMETER

Flash Point. To estimate the flash point of an oil, a special apparatus is required, consisting of a copper container or oil cup with a stirring device, a thermometer, and a test-flame jet, the container being mounted on a stand high enough to allow of a Bunsen burner being placed beneath, to heat the oil.

The test sample is put in the oil cup, and when the oil starts to warm up, a cap is fitted over the cup, and the oil is then continuously stirred, except when the test-flame is inserted. The temperature reading on the thermometer is carefully watched, the small gas test-flame being inserted at every 2° F. rise in temperature until a flash takes place. The actual temperature when the flash occurs is then recorded, and this is known as the *closed flash point*.

Specific Gravity. The specific gravity of oil is ascertained by the use of a Baumé hydrometer, which is used in the same manner as any other hydrometer, the reading on the scale being taken as the surface of the liquid. The standard Baumé scale begins at 10° for a specific gravity of 1 (as pure water), and increases as the specific gravity decreases, in accordance with the relationship—

$$\text{Specific gravity} = \frac{140}{130 + \text{Baumé scale}}$$

or

$$\text{Baumé scale} = \frac{140}{\text{Specific gravity}} - 130$$

It is usual to take the specific gravity at 60° F.

For high-speed spindles a good machine oil should be used, with a closed flash point of about 250° F. (minimum). The specific gravity should be from 0·830 to 0·865. For plain-bearing motors, countershaft bearings, etc., such oils as "Vacuum A" or "Houghton's L 1½" absorbed oils are advised. For air compressors, best-quality medium oil, having a high flash point, say 385° F. (minimum), should be used, as oil with a low flash point becomes vaporized with the air, for which reason a good oil film does not form on the cylinder walls. "Palmerine" compressor oil will give good results. For chains and heavy gearing, a graphited oil may be used, the oil serving to conduct the graphite to the part that requires lubrication.

For high-speed ball-bearing shafts, it is better if the ball bearings run in an oil bath using a very light good-quality machine oil, as mentioned above; but for medium and low speeds a good acid-free grease should be used with an acidity or alkalinity of not more than 0·1 mg.

Where moving metal parts are subject to heavy or vibrating loads, pitting and corrosion sometimes take place, even though the parts may be well lubricated with a good acid-free oil or grease. Much research has been carried out to find the cause, and it is considered that the trouble is mechanical, electrical, and chemical. Messrs. Alexander Duckham & Co., Ltd., state that when two metal surfaces are suddenly brought together under pressure, an electrical stress is produced at, and around, the point of contact. When the action is repeated continuously, alternating electric stresses are produced, the potential difference being responsible for the pitting; moreover, the slip which invariably takes place on moving parts has an

abrasive action, and the heat generated causes oxidization. Zinc oxide has been added to the lubricant in colloidal form, which makes the lubricant anodic to steel and creates an electrolytic couple which forms an adherent film on the contacting surfaces, thus preventing corrosion and pitting. This new lubricant is known as "Keenol" and is marketed by Messrs. Alexander Duckham.

THERMOMETERS AND PYROMETERS

The necessity for recording temperatures arises in almost every industry, and it is essential for the engineer to be conversant with each type of thermometer and its field of application.

Temperature. There are three thermometer scales in use to-day: Fahrenheit, Centigrade, and Réaumur, but the latter is only used in some parts of Central Europe. The freezing point of water is taken as zero on the Centigrade scale and 32° on the Fahrenheit scale, the boiling point being 100° Centigrade and 212° Fahrenheit.

Conversion Formulae—

$$\text{Fahrenheit to Centigrade: } \frac{5 \times (\text{degrees F.} - 32)}{9} = \text{degrees C.}$$

$$\text{Centigrade to Fahrenheit: } \frac{9 \times \text{degrees C.}}{5} + 32 = \text{degrees F.}$$

Absolute Zero. Whilst it is usual to measure from the zero of a particular scale, temperature is sometimes expressed in *degrees absolute*, which are reckoned from absolute zero. This conception has been arrived at by theoretical calculations, and is taken as the lowest point to which it is conceivable for temperature to drop. It can be arrived at by adding the following numbers of degrees to the scale which is being used—

Absolute zero = scale reading in degrees Fahrenheit + 459°.

Absolute zero = scale reading in degrees Centigrade + 273°.

Thermometers. Perhaps the most important feature of any thermometer is its sensitiveness. The amount of "lag" in a cheap type may be considerable and may indirectly cause much damage to work undergoing certain processes involving heating to definite temperatures.

There are many ways of indicating or recording temperatures, and the following is a brief description of the various types of apparatus available.

For ordinary purposes the mercury-in-glass thermometer is perhaps the most useful, for temperatures up to 950° F., but it must be borne in mind that the sensitivity depends entirely on the medium in which it is immersed. The mercury-in-steel thermometer may have less lag than one of the mercury-in-glass type if the medium is water; whereas with air the reverse may be the case,

due to the fact that the lag is dependent on the relationship between the rate at which heat can be absorbed by the bulb and the mercury and the rate at which heat is brought by the medium to the bulb. Circulation of the medium, of course, has a great influence on the temperature, and whichever type of thermometer is used, care must be taken to see that the bulb is placed in the best position to give an average temperature. Particularly is this so in the case of drying ovens heated by steam coils or by electrical means, where a uniform

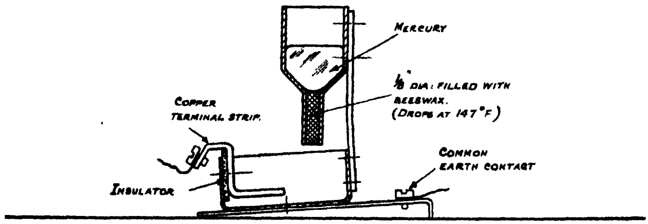


FIG. 198. CONTACTS USED WITH LAMP OR BELL INDICATOR TO FIND HOT SPOTS IN DRYING OVENS, ETC.

temperature is required. It is not always possible to arrange a forced air circulation around the work to be dried, and a good method for checking temperature distribution is to make up a number of small contacts, as shown in Fig. 198, and to connect them in circuit with a dry battery and a bell or lamp. A solder or wax with a melting point equal to the maximum required temperature is used to hold up the contact, and by noting which contact falls first, and then by moving the contacts to different positions in the oven, it is possible to find the hot "pockets" and to arrange for baffles to promote a more uniform heat throughout the oven. By this means the best position for the insertion of a thermometer bulb can also be found. Actually, the best position for the bulb is not always the most convenient for reading the scale; it is therefore necessary in such cases to install a distance thermometer of the indicating or recording type. Whilst ether vapour or a spirit is sometimes used, mercury is the best transmitting medium, as it exists in liquid form over a wide range of temperature; it is a good conductor of heat as compared with other liquids; it has practically uniform expansion, low specific heat, and the commercial quality is very pure. The mercury-in-steel thermometer is therefore the best instrument of this type. It is not advisable to buy cheap instruments, as a number of errors can creep in due to hysteresis effects, to poor calibration, to bending of the capillary tube, to change of temperature of the indicator, to movement errors, etc.

The mercury-in-steel thermometer is composed of a bulb and a Bourdon gauge connected by capillary tubing, the whole being

filled with mercury and calibrated to suit the scale. For temperatures up to 1 200° F., with capillary tube lengths of not more than 75 ft., this system will give good service (Fig. 199 (*a*)).

Electrical Thermometers and Pyrometers. These are usually of the resistance, thermo-couple, or optical types, and are used for work at higher temperatures, such as the heat treatment of metals and alloys.

RESISTANCE TYPE. This type is based on the principle of the

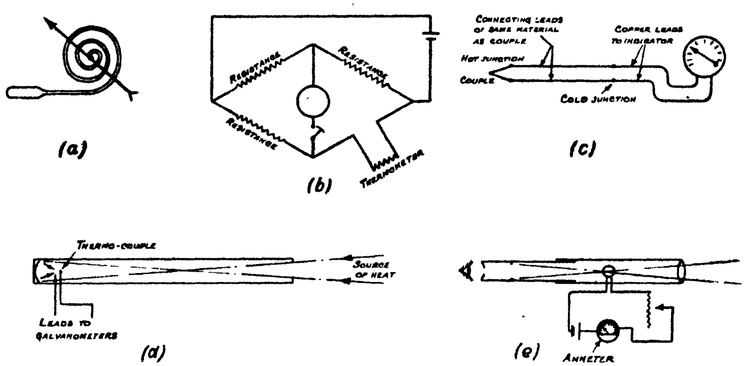


FIG. 199. TYPES OF THERMOMETERS AND PYROMETERS

Wheatstone Bridge; in this case the resistance of a coil of wire or similar element changes with its temperature and this change is measured on the galvanometer or indicator by putting the coil in circuit with the fourth arm of the bridge, as shown at (*b*) in Fig. 199. This type is generally used for temperatures up to about 500° F.

THERMO-COUPLE TYPE. These thermometers may be of the base-metal or rare-metal type. The base-metal thermo-couple may be used for temperatures up to about 1 800° F., but for higher temperatures a rare-metal thermo-couple should be used.

The principle is briefly this: two wires of dissimilar metals are joined together to form what is known as a *hot junction*, and are connected by cables to the indicator, which is a sensitive milli-voltmeter and is known as the *cold junction* (Fig. 199 (*c*)). When heat is applied at the hot junction, the thermo-electric force generated will be proportionate to that heat, provided that conditions at the cold junction remain constant; and this force is indicated on the milli-voltmeter. In the base-metal type, nickel or nickel-chromium alloys are usually employed, and in the rare-metal type, platinum or platinum-rhodium alloy.

Thermometers or pyrometers of the thermo-couple type are usually sent out by the manufacturer with the resistances balanced to suit the existing distance between element and indicator. A slight

alteration in length will not affect the instrument, but with the resistance or Wheatstone bridge type it is essential to standardize to a known resistance. The exact length from the element to the instrument should therefore be stated when ordering from the makers. The cable for the resistance type is usually of the three-wire pattern to compensate the instrument for any changes in temperature around the cable.

RADIATION TYPE (Fig. 199 (*d*)). These pyrometers are operated by focusing the radiant heat from, say, a furnace, by means of a concave mirror on to a small thermo-couple, which causes a deflection in a galvanometer, proportional to the quantity of radiant heat.

OPTICAL TYPE. This form of pyrometer consists of a telescope with a small lamp mounted in it, the filament of which can be focused and so viewed at the same time as the heated body whose temperature is to be measured. The current passing through the lamp is adjusted by a resistance until the red spot of the filament exactly matches the colour of the body whose temperature is being measured. The current reading on the ammeter in the circuit, which is calibrated to a temperature scale, gives the actual temperature reading (Fig. 199 (*e*)).

For thermometers of the mercury-in-glass or mercury-in-steel types, Messrs. Negretti & Zambra are perhaps one of the best-known makers; and for the electrical type such firms as the Cambridge Instrument Co., Fosters, and Electroflo, are well known.

*p*H VALUES OR HYDROGEN-ION CONCENTRATION

The symbol *p*H is becoming more and more part of the engineer's vocabulary, and the physical condition which it denotes has an important bearing on so many processes as to become, in a number of industries, an accepted operating factor; therefore this book would not be complete without a reference to it.

It is well recognized that acids and alkalies are factors of great importance in chemical and biological processes, and to-day the measurement of effective acidity in solutions is not only a duty of the works laboratory but is becoming more and more a matter of works routine for certain processes such as water purification, control of works effluent, reduction of corrosion in boilers, electro-deposition of metals, food industries—in fact, general industrial chemistry.

Whereas titration can only give an idea of the *quantity* of acid or alkali present in the solution, the measurement of hydrogen-ion concentration gives the *intensity* or effective acidity or alkalinity, which is much more important in industrial processes.

The actual hydrogen-ion concentration in water, for instance, is very small indeed, and its determination involves complicated calculation. To render this calculation as simple as possible, the unit values or *p*H figures suggested by Professor Sörensen are now

recognized as standard. In this pH scale, which runs from 0 to 14, distilled water is taken as neutral with a pH value of 7, and the scale may be likened to a thermometer scale. As the pH value increases, the acidity decreases; therefore from 7 to 0 gives the degree of acidity and from 7 to 14 the degree of alkalinity.

To cite one case where pH values can be of definite use to the works engineer: there is the question of corrosion in boilers and boiler tubes. Whereas trouble is often caused by dissolved oxygen in the feed water, trouble due to wrong pH values is equally important: it can be corrected by controlling accurately the amount of caustic

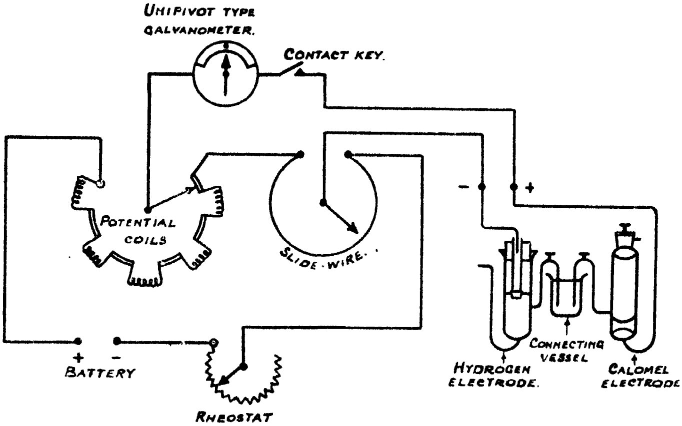


FIG. 200. WIRING DIAGRAM OF POTENTIOMETRIC METHOD OF OBTAINING HYDROGEN-ION CONTENT

soda "dosed" into the softening plant. By this control the pH value of the feed water can be kept at 9·5 to 10, which is the ideal condition of some feed waters. For condensers, the pH value should be as near to pure distilled water as possible, i.e. 7. A large number of works have electro-plating plant, and it is a well-known fact that slight alterations in the effective acidity of a vat may seriously affect the finish of the work, and here again recognized pH values are available to which the vat must be worked for ideal finish. Space will not permit the mention of the many other cases where pH values are of real concern to the engineer.

Whilst there are several methods of determining pH values, they are of two main types—*colorimetric* and *potentiometric*, the latter being recognized as more accurate. The basic standard of measurement is the hydrogen electrode, and the pH value of a solution can be determined by measuring the potential difference between the hydrogen electrode and a standard reference or calomel electrode, both electrodes being immersed in a bath of the solution to be tested. The principle of potentiometric measuring instruments will be apparent from Fig. 200.

There are a number of instruments on the market for the measurement of pH values. Mention may be made of Messrs. Baird & Tatlock, and the Cambridge Instrument Co., both of whom make several types of such instruments, either for research or for routine measurements, the latter firm marketing a compact recorder which is in effect a recording potentiometer. A new development for general works use is Messrs. George Kent's "Multelec," Fig. 201, which can be employed where any variable condition in the plant can be made to give rise to variations in electrical resistance or potential.

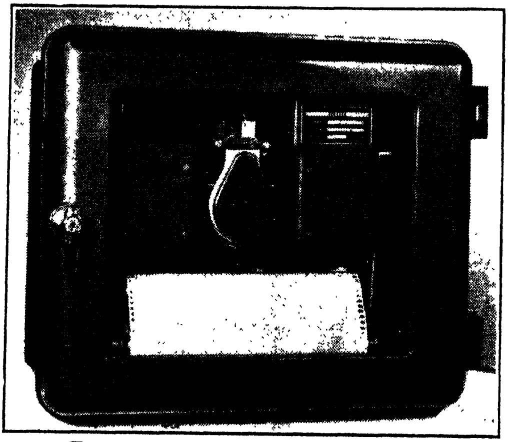


FIG. 201. MULTELEC pH RECORDER
(*George Kent & Co. Ltd.*)

The instrument is made in single- and multi-point form. The key feature of the instrument is the sensitive and robust galvanometer of the double-suspension type which detects immediately the slightest change in the conditions being measured. A deflection of the galvanometer pointer is transmitted by setting levers to an arm which normally is in the horizontal position. At intervals of 2 sec. this arm is clutched by a disc, and a pair of cams restore the arm to its horizontal position, thereby rotating the disc by an amount proportional to the movement of the galvanometer needle, without placing any restraint on the latter.

The disc in turn rotates a robust shaft carrying this slide-wire disc which controls the movement of the recording device. As a result of the manner in which the movement of the galvanometer pointer is transmitted, a very small deflection, in fact as little as $\frac{1}{1000}$ in., is reproduced faithfully on the chart.

The instrument is readily adapted for control purposes by the addition of either an electrical floating controller or an air-operated controller of the "proportional" type.

CHAPTER XII

TIMBER DAMAGE DUE TO INSECTS AND DRY ROT

THE amount of damage caused by the boring of different insects or the ravages of dry rot has only been fully realized during the past few years. Although damage by beetles and that due to dry rot are totally different—the former being caused by an insect and the latter by a fungus—it is proposed to deal with these two subjects under the general heading of "Timber Damage."

BEETLES

Some time ago the author had experience of the amount of damage that can be caused through insects. An oak fence which surrounded part of a works appeared to be "powdering," apparently due to dry rot. On inspection, however, it was found that the boards were covered with small holes about $\frac{1}{16}$ in. diameter; a thorough examination was made and, on cutting away some of the wood, small beetles about $\frac{1}{6}$ in. long were found. Samples were sent to the Forest Products Research Laboratory at Princes Risborough, Bucks, and an entomologist came and inspected the fence. The damage was found to be caused by the *Lyctus* powder-post beetle, and the greater part of the fencing had to be burnt. The infection seemed to have been contracted from a nearby hardwood timber store in which imported oak had been stored. Unfortunately, due to the length of the life cycle, it is impossible to detect the trouble until some nine or ten months after the start of the damage; this is due to the fact that the damage is done by the larvae and not by the bettle. Fig. 202 shows the death-watch, furniture, and the *Lyctus* beetles, and their larvae.

Lyctus Powder-post Beetles. These beetles derive the name "powder-post" from the manner in which their larvae reduce the timber to a fine powder. They are of an elongated shape, the length being about $\frac{1}{6}$ in.; their colour varies between reddish-brown and black. Altogether there are about twenty species of the *Lyctus* beetle, but only four are usually met with in this country. The commonest species is *Lyctus Brunneus*, which was originally a native of South America, but is now cosmopolitan. The author has found *Lyctus Planicollis* in a parcel of American oak. The life cycle occupies about twelve months. The beetle lays its minute eggs in the vessels of the sap wood, from April onwards. When the eggs hatch out—from eight to fifteen days later—the grubs begin to tunnel along the grain of the wood, feeding and growing until the next spring, and it is during this stage that the damage is

done. The beetle bores its way out of the wood from April until June and restarts the life cycle.

The beetle attacks oak, walnut, hickory, sweet chestnut, ash, etc., and always attacks the sapwood; it does not attack softwoods. Where timber is affected, the grubs can be killed by kilning at 130° F. for one hour, or by spraying with an insecticide such as "Cuprinol." The beetle only attacks seasoned or partly seasoned wood, and cannot lay its eggs on a varnished surface; therefore, as the infection

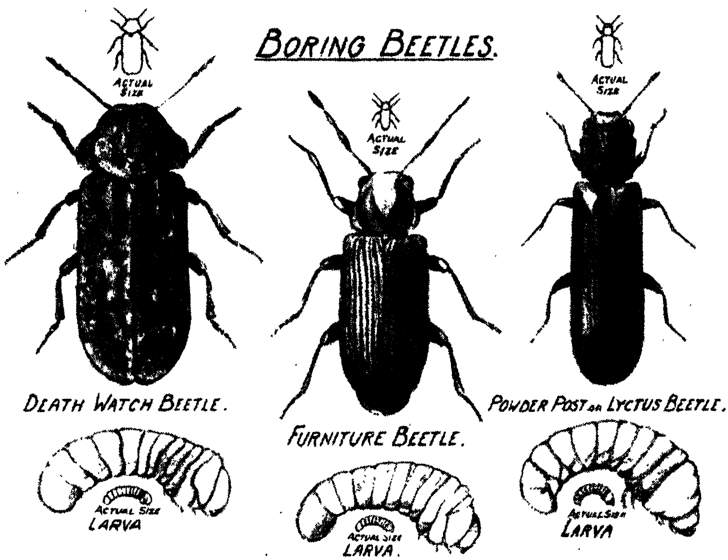


FIG. 202. BORING BEETLES

is usually derived from piles of imported hardwoods, every effort should be made to avoid keeping a stock over a long period, using softwood "sticking" so that the infection cannot be carried by this means. Timber stores or yards should be kept clean and lengths of sapwood should not be allowed to accumulate. The spraying of all incoming woods with a suitable insecticide will stop the infection.

The *Lyctus* beetle can always be identified by the finely powdered wood formed during the tunnelling; this will drop from the holes on tapping the affected piece of wood. The holes vary in size up to $\frac{1}{8}$ in. diameter for some of the species.

Pinhole Borers. These beetles are true forest insects and do not affect seasoned timber; they only attack standing trees which are partly diseased, or hard and soft logs immediately after or within a short period of being felled. Moisture is necessary to the life of

the grub, as the beetles bore into the wood and their larvae feed on a fungus which grows on the walls of the tunnels which the beetles have bored. This fungus is known as *ambrosia* and, as moisture is necessary for its growth, the grubs always die when the wood is dried out. These beetles can be distinguished from the *Lyctus* species by the absence of powder in the tunnels, which are darkly stained. Moreover, the tunnels run across the grain of the wood, whereas those of the *Lyctus* beetle lie along the grain.

Longhorn Beetles. These form another family of beetles which are found both in home-grown and imported timber; but, like the pinhole borers, they are true forest insects, so that they do not affect seasoned or partly seasoned timber. The eggs are laid in the bark of the trees, and on hatching out the larvae bore into the sapwood, making holes which may vary in diameter up to $\frac{1}{2}$ in. They do not often attack the heartwood. Beech is a wood in which they are frequently found.

So far the only beetles which have been dealt with are those which attack hardwoods before or during seasoning. There are, however, other species which do an equal amount of damage and can live in old and well-seasoned timber. The chief of these are the common furniture beetle and the death-watch beetle.

The Common Furniture Beetle (*Anobium punctatum*). This is very closely related to the death-watch beetle and is perhaps more widely distributed than any other species. There is very little difference between the shape of the furniture beetle and that of the death-watch beetle, except that the former are smaller; they vary from reddish- to dark-brown in colour and are usually from $\frac{1}{8}$ in. to $\frac{3}{16}$ in. long, the larvae being similar in shape to those of the *Lyctus*. Any seasoned woods, hard or soft, may be affected; but more especially is the species found in old furniture, from which it derived its name.

The beetles emerge between June and August, laying their eggs — about twenty in number—in cracks or crevices on the surface of the wood. The eggs take about three or four weeks to hatch, and the larvae then start to bore into the wood in all directions, the tunnels becoming larger as they grow. When the affected timber is out of doors, i.e. under natural conditions, the life cycle takes about a year, but indoors it may take from two to three years. When the life cycle is nearly complete, the larva comes up near the surface of the wood, making a cavity in which it changes to the pupa or chrysalis. After three to four weeks the cycle is complete, and the beetle bores its way out of the wood, leaving what is known as a *flight-hole*, about $\frac{1}{16}$ in. in diameter. The powder produced by the larvae of these beetles is in the form of very small oval pellets.

Death-watch Beetle (*Xestobium Rufo-villosum*). This belongs to the same family as the common furniture beetle, and is similar in shape but slightly larger—$\frac{1}{4}$ in. to $\frac{5}{16}$ in. long—the colour being dark

brown, with small patches of short yellowish hair which gives a mottled appearance. It usually attacks well-seasoned hardwood timbers of large size, especially oak, and occasionally may be found in old dry softwood timbers.

It derives its name from the peculiar "ticking" sound that it makes, which is thought to be a call between the sexes. The length of the full life cycle is not yet known, but it is considered to occupy more than three years and may even exceed four years. The beetles emerge between April and June, laying their eggs—about seventy in number—in cracks and crevices, after the manner of the furniture beetle. The eggs hatch out after from two to eight weeks, depending on the atmospheric conditions.

The larva bores into the timber for a period of two years or longer, eventually turning into a pupa in the autumn. The completion of the cycle then takes about four to six weeks, when the beetle emerges from the timber, leaving a "flight hole" about $\frac{1}{8}$ in. in diameter. The wood dust is ejected from the tunnels in the form of small bun-shaped pellets.

Treatment with a special insecticide such as "Cuprinol" will eventually cure the infected timber, but it is always advisable to consult experts in bad cases.

DRY ROT

The damage caused by dry rot is considerable, and more often than not could be eliminated, as it is generally due to lack of proper seasoning, inadequate ventilation, and moisture. Whereas the damage caused by beetles is due to tunnelling, dry rot is a decay due to the growth of a fungus feeding on the affected timber.

The name "dry rot" is a misnomer, as the fungal growths need moisture for their existence; actually the name is derived from the dry and brittle appearance of the affected timber.

There are several species of dry rot and space will not permit of more than a brief description of some of the more common species.

Merulius Lacrymans. This is by far the most malignant and widespread species met with in this country; it has a preference for the sapwood of softwoods, but will also attack the hardwoods. It requires moisture, air, and heat for its growth, but if there is an excess of any one of these factors it will not thrive; thus still, damp air, such as that in an unventilated cellar, will cause active growth, which takes the form of soft, snowy-white "cushions." When it is exposed to light, bright yellow patches will appear, sometimes producing drops of moisture. Under some conditions it will form skins of a grey or light yellow colour with patches of bright yellow or lilac. Perhaps the most destructive feature of the dry rot fungus is that it can form strands varying in thickness from a thread to that of a lead pencil, which can spread over inert substances such as brick or stone walls or metal, to feed on the wood

which it digests and converts into sugars; it can even penetrate through brick walls.

These strands carry a reserve of moisture and food, which enables the fungus to thrive on other timber which is comparatively dry, but which eventually becomes infected. After a time a fleshy outgrowth of "fruit" body is formed, which disseminates millions of microscopical spores which can carry the infection to other areas.

Wood, after being attacked by this fungus, becomes light and dry, powdering under pressure; it has the appearance of charred wood, except for the colour, which is brown.

Poria Vaporaria. This type is usually found in the timber of damp mines, but is occasionally found in houses. In appearance it is somewhat like *Merulius* and its method of attack is similar, but it requires more moisture for its growth. It can be distinguished from *Merulius* by the fact that the growths remain white or cream-coloured, and do not show secondary patches of yellow or tinges of lilac. The strands are never thicker than fine twine and it has the appearance of a fine feathery seaweed. The "fruit" body is white, with deep pores.

Coniophora Cerebella. This is known as the "cellar fungus"; it only attacks timber which is very wet. The strands are slightly thicker than those of *Poria* and vary in colour from yellowish brown to black; thick cushions are never formed by this species.

Its effect on the timber is to cause longitudinal splitting, the colour changing to dark brown. The "fruit" body is irregularly shaped and has a skin of olive brown, covered with small lumps. It is much easier to kill than the former growths; all that is necessary is to dry out the affected timber.

Paxillus Panuoides. The attack from this growth is similar to that of *Coniophora*, but it is not so frequently met with, although in a very damp area it can do a great deal of serious damage. The strands, which are fibrous, are of a yellowish colour, sometimes showing vivid violet tints.

The affected timber is stained a bright yellow, which eventually deepens to a dark reddish-brown. The "fruit" body, which is of a dirty yellow colour, is soft and fan- or shell-shaped.

Treatment. The best way, of course, is to *prevent* dry rot altogether. Where timber is to be used in a damp place, it must be creosoted under pressure with a good quality of creosote, so that the latter penetrates right into the wood. Alternatively, the timber may be treated with some special preservative having good powers of penetration. Adequate ventilation should be provided.

The presence of dry rot can be detected by a damp musty smell, by warping and surface cracks in floor and skirting boards, and by the presence of a fine rusty red powder, which is actually the fungus spores.

When dealing with an infected area, the first aim should be to

find the source of the trouble, which may be a leaky drain, rain-water pipe, or gutter, or insufficient ventilation. All infected timber should be removed, and if the attack is very bad, all cement joints in the brickwork should be scraped out and the brickwork thoroughly heated with a blowlamp; this should be followed by treatment with a special preservative. All rubbish must be removed afterwards and the area thoroughly cleaned, as the rubbish and debris may be full of fungus spores. The new woodwork should be free from sapwood and knots, and should be well seasoned. It should be well creosoted or treated with a preservative, such as "Cuprinol." If these simple precautions are taken, dry rot should be eliminated.

The author is indebted to the Technical Department of Messrs. Cuprinol, Ltd., for much help; he has also used information contained in the publications of the Forest Products Research Laboratory.

If timber damage is experienced, due either to beetles or to dry rot, it is advisable to consult the Forest Products Research Laboratory, who will give every assistance in their power, if necessary sending an entomologist or a dry rot expert, for whose services they make only a nominal charge.

Wood Seasoning or Kilning. When installing kilns it is usual to consult a firm of specialists, although the actual erection of a kiln is not beyond the Works Engineer. The Forest Products Research Laboratory will always assist with advice. It may also be mentioned that they will give every assistance in the training of an operator, and in every other way, to ensure that timber is properly seasoned.

Space will not permit of a description of different types of kilns, but when considering any particular design, care must be taken to see that the air ducts to and from the drying chambers are so arranged that they provide good circulation throughout, without "dead" air pockets; also that fans, heaters, and humidifiers are so arranged as to afford easy and efficient control. Before taking over a new plant, smoke tests should be made to check the circulation and to ensure that air passes through all parts of the timber stack, the kiln, of course, being loaded for the trial. There is usually enough room to pass along the wall sides, for observation purposes. Tests must also be made to ascertain whether the required temperatures and humidities can be realized.

It should always be remembered there are three main points to consider in connection with the successful operation of the kiln: temperature, humidity, and circulation. It is thus essential that the control arrangements should be easily adjustable, and that the operator should be fully conversant with their working.

Steam consumption is dependent on the size of the kiln, the load, and many other factors, so that it is impossible to give any actual figures; however, a few remarks on probable heat losses may be useful. Air losses between the heater and the chamber, also the

radiation losses from chamber and steam piping, may be in the region of 20 per cent. It is, therefore, essential that reasonably airtight doors should be fitted and that the chamber and piping should be efficiently insulated. Interchange of heat with the air is another source of loss if due care is not taken in operating the plant. Where timber-drying plant is employed, every engineer knows that occasionally a few planks may pass through without being thoroughly dried, perhaps due to a change of operator. If this should happen, the plant should be first examined to ascertain whether the steam has been accidentally shut off, the sprays choked, or the fan stopped. It is therefore proposed to deal with the operation of the plant and not the design, as in most cases the trouble may be due to bad stacking of the timber or inefficient operation. The engineer must see that the plant is in efficient working order, especially the temperature and humidity recorders, which provide a means of checking the actual conditions. Since a timber kiln dries timber by the action of a stream of hot moist air, the maintaining of a high humidity enables the drying process to be carried out at high temperatures, which accelerates the seasoning process.

The temperature of the air will depend on the class of wood to be kilned. For softwoods it may be as high as 80° C. With refractory hardwoods, such as oak, the kiln may start between 35° to 40° C., rising to about 55° C. With other hardwoods, which are more easily dried, the temperature may be between 50° and 90° C. The humidity is perhaps more important than the temperature, and the Forest Products Research Laboratory has prepared a suggested kiln-drying schedule for different woods and moisture contents, a copy of which they will send on application. The air speed through the pile need not exceed 1½ ft. per sec., and is much slower in many kilns. At the end of the seasoning process it is essential that the temperature should be reduced slowly, so that the surface of the wood is not injured by sudden contact with the cold air; this, of course, applies specially to hardwoods. Periodic tests should be made towards the end of the "run," and test pieces checked for moisture content. The appropriate times for kilning are usually indicated on the hygrometer chart.

Stacking of Timber. The piling sticks should be kept strictly vertical one above the other directly over the floor battens. Support should always be provided at the ends, and clear airways between the pile should be prevented. A canvas screen may be used, if necessary, to cover the top of the pile, thus preventing a short-circuit of the air. An air space of 1 in to 1¼ in. between timbers is recommended.

12—(T.43) 20 pp.

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		Superheat Engineering Data.	The Superheater Co. Ltd.	T.H.
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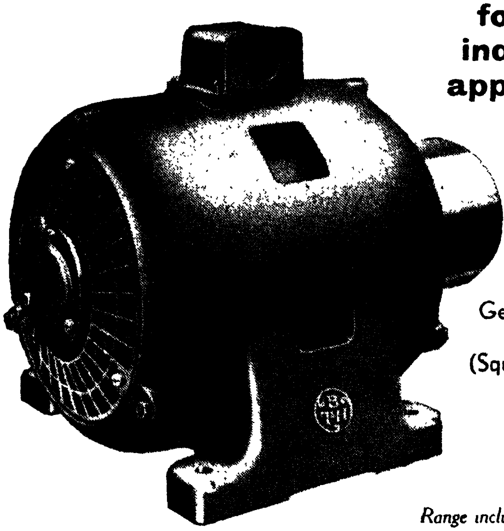

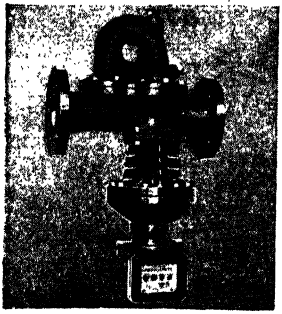

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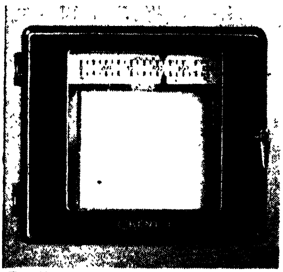

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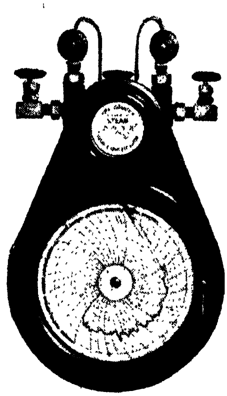

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